MACROINVERTEBRATE BOTTOM FAUNA OF THE GAMBIA RIVER, WEST AFRICA

by

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INTRODUCTION

This study is part of the Gambia River Basin Study (GRBS) conducted by The University of Michigan during 1983-1984. The GRBS was divided into four sub-studies dealing with four topics: aquatic resources, public health, wildlife/vegetation, and socio-economics. The objectives of the four sub-studies were approximately the same, although somewhat modified to accommodate each individual discipline. A major, if not the main objective of the GRBS, was to produce a good understanding of the extant river basin system. This document presents results from the aquatic resources sub-study; more specifically, this document presents the results of the study of the benthic invertebrates of the Gambia River. Two general topics in regard to benthic invertebrates are covered below. First is the discussion of base-line data concerning the benthic invertebrates of the river, including their role in the stream ecosystem. Second is an assessment of the possible impacts of river impoundments on the existing invertebrate bottom fauna.

Previous work on benthic invertebrates of the Gambia River have almost exclusively concerned the mollusk fauna. Monteillet and Plaziat (1979) discussed the geographical distribution and ecology of mollusks in the tidal area and lower reaches of the river. Mollusk species occurring in the segment of the Gambia River located in the Niokola Koba Park were discussed by Daget (1961). Few data were available on other invertebrate groups of the Gambia River. During this study, a large variety of invertebrate groups was sampled in order to establish the composition of the benthic communities living in the different river habitats.

The Gambia River basin lies between 11°30' and 15°00' latitude North and 11° and 16°30' longitude West (Fig. 1). It stretches into the Republic of

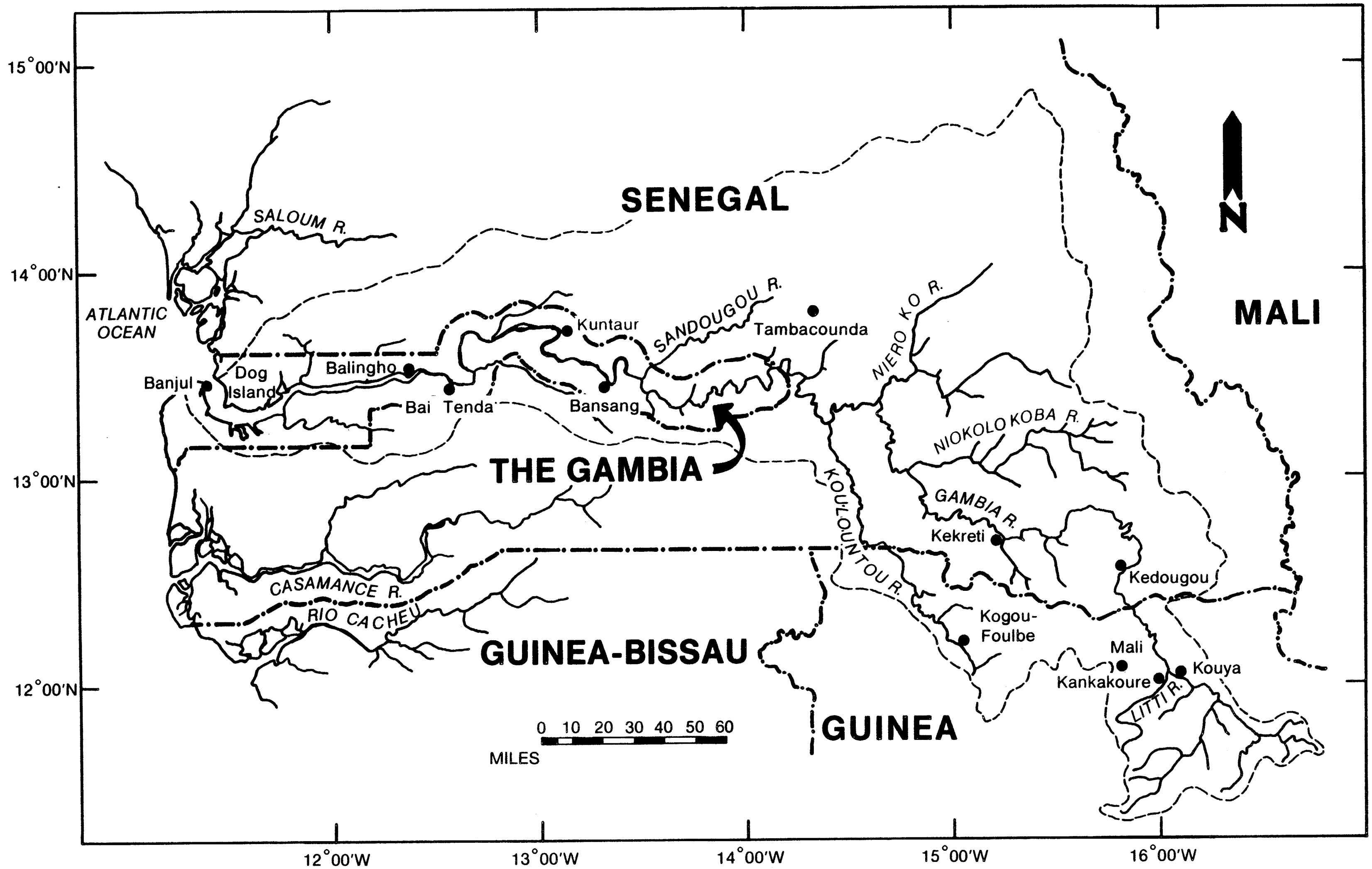


FIG. 1. Drainage basin of the Gambia River, within dashed line.

Guinea, Senegal, and The Gambia. The Gambia River, with a length of 1,180 km, has its source near Labé in the Fouta Djallon massif of the Republic of Guinea, at an altitude of 1,150 m.

The river basin is subject to a tropical climate, characterized by a long dry season from November until May and a rainy season lasting from June to October. Rainfall varies considerably from year to year, both in quantity and distribution, with the highest precipitation in August. During the dry season two transitional periods can be distinguished: cool and dry from November to January, and hot and damp, but without rain, from mid-May to June. During the annual flood, saltwater penetration, which may reach inland as far as 240 km during the dry season, is pushed back toward the sea. Fresh water inundates the flood plains and partially washes out the salt deposited during the dry season.

A development program has been proposed for the Gambia River which includes the construction of up to five dams on the river and an extensive irrigation network. Within the scope of the Gambia River basin development program the following projects have been proposed:

A salinity barrage at Balingho, in The Gambia, to control the saltwater intrusion upstream into the river and to store fresh water for irrigation. After construction of the barrage the river upstream from Balingho will be permanently flooded with fresh water.

The Kekreti dam in Senegal, to provide sufficient fresh water for irrigation and production of electricity.

The Kouya dam, situated on the Gambia River, 6 km upstream from its confluence with the Litti, in the Republic of Guinea.

The Kankakoure dam, on the Litti near its confluence with the Gambia River.

The Kogou Foulbe dam, situated 80 km into the Republic of Guinea, on the Koulountou, another tributary of the Gambia River. Each of the three dams proposed for Guinea will be primarily used for the generation of hydropower.

METHODS

STUDY AREA

Five major river zones were identified and sampled by the River Resources Team (Moll and Dorr 1983). These zones are:

Lower estuary. In this zone salinities are high throughout the year (>30 ppt); the flora and fauna are composed of marine species. Main sampling site: Dog Island.

Upper estuary. The salinities vary from 0 to 30 ppt and this stretch of the river is bordered by extensive mangroves. Main sampling site: Bai Tenda.

Lower river. The water is fresh throughout the year, but has distinct tidal fluctuations. Main sampling site: Bansang.

Upper river. Tidal influence is no longer perceived and the river is primarily a slowly running stream, but with occasional rapids. Main sampling site: Kedougou.

Headwaters. The Guinean headwaters of the Gambia River consist of predominant streams with rapids and pools, flowing through a hilly and mountainous terrain. Main sampling site: near the bridge across the Gambia River, south of Balaki and east of Mali (Figs. 1 and 7).

In addition to the sites mentioned above, the Kekreti dam site, located in the Niokola Koba Park, was sampled.

SAMPLING STRATEGY

Sampling methods and gear were adapted to the specific characteristics of the different river zones studied as follows:

Lower estuary. Initially, a Ponar grab was used to sample benthos in this river zone. However, due to the soft muddy nature of the bottom in the estuary and the very limited size of bottom surface sampled with this kind of gear, the results were poor and this technique was abandoned. A more productive approach was to examine catches from trawls carried out by the R/V Laurentian, the research vessel of The University of Michigan, in the main channel of the river, and from gill nets set for fish samples. These nets provided sufficient specimens to obtain an idea of abundance and spatial distribution of the macroinvertebrates in the lower estuary. Furthermore, seining along the river banks yielded some additional specimens of the benthic fauna near Dog Island. The trawl used for collecting benthos samples was of the semi-balloon type, shrimp try net design, having a 3.0-m headrope and 3.6-m footrope; body and cod end were composed of 1.9-cm mesh, the cod end interliner was composed of 0.6-cm mesh. The gill net was composed of twelve 3.0-m panels with netting of the following mesh sizes: 1.3 cm, 1.9 cm, 2.5 cm, 3.2 cm, 3.8 cm, 4.4 cm, 5.1 cm, 5.7 cm, 6.4 cm, 7.0 cm, 7.6 cm, and 10.2 cm. The size of the net was 1.8 m x 36.6 m. A seine of 1.8 m x 15.2 m was used, with a 1.8 m x 1.8 m x 1.8 m bag; the mesh width was 0.6 cm.

Upper estuary and lower river. As in the lower estuary, the bottom of the upper estuary and lower river consists mainly of soft mud. Ponar samples taken in this soft sediment yielded very few animals. Benthic tows with a # 000 plankton net were also not very successful. Because of the considerable depth of the river (15-20 m) in the mid-channel, as well as near the river

banks, sampling by means of a dip net was impossible in this stretch of the river. Data concerning the benthos were mainly provided by the catches from the gill nets set for fish sampling, from trawls, and a benthic dredge. The latter was used along the river banks of the upper estuary and lower river, and in the bolons (creeks).

Upper river. The depth of the river near Kedougou was such that benthos could be collected by means of a dip net. The net, originally designed as fish net, was transformed into a benthos net by lining it with mosquito netting. Sampling of different habitats within the river zone was adopted, rather than sampling at regular intervals in the river. The latter approach entailed the risk of sampling the same kind of micro-environment several times, whereas other habitats may not be represented among the samples. Benthos samples were taken during the day, night, dusk, and dawn to evaluate possible differences in activity of the bottom invertebrates at different times of the day.

The micro-environments were selected according to stream velocity, bottom substrate, and the presence or absence of aquatic vegetation. Each habitat was sampled in an "exhaustive" way to obtain a maximum of taxonomic diversity. *In situ*, the animals were separated from plant debris and substrate and stored in 4% formalin. Entire samples were preserved to allow an estimation of relative abundance and identification of taxa characteristic for a particular river habitat.

Headwaters and Kekreti dam site. The same gear and sampling strategy as in the upper river zone were used in the headwaters zone. Samples were collected during the day, dawn, and dusk. Night samples were not collected in the zone.

SAMPLE PROCESSING

The samples of the bottom fauna were analyzed at the GRBS Headquarters in Banjul, The Gambia. The smaller invertebrates, represented mainly by insect larvae, were identified and counted under a dissection microscope. Because of the lack of appropriate keys, many animals could not be identified to the species level and rather were identified to a higher taxonomic level (genus, subfamily, or family). Mainly the following keys were used: For the freshwater fauna, "Introduction a l'étude des macroinvertébrés des eaux douces" by Tachet et al. (1980) and "Flore et Faune aquatiques de l'Afrique Sahélo-Soudanienne" by Durand and Leveque (1980); for marine benthos, "F.A.O. species identification sheets for fishery purposes, Eastern Central Atlantic" by Fisher et al. (1981).

In addition to species counts, estimates of age, biomass, and length or width were made of the shrimp and crab specimens. For the shrimp in the trawl and gill net samples, the length of the cephalothorax (carapace) was measured from the orbital notch to the posterior dorsal margin, and the body length was measured from the orbital notch to the tip of the telson (tail fan). The length and width of the carapace were measured for crabs belonging to the genus *Callinectes*.

DATA ANALYSIS

A taxonomic list of the benthic invertebrates collected was established for each zone. The relative abundance of different invertebrate groups in each river habitat was calculated as follows:

$$\text{Relative abundance} = A = \frac{\text{number of animals per taxon}}{\text{total number of animals in sample}}$$

The correlation between cephalic length and body length was calculated for the main shrimp species as were size class frequencies. For *Callinectes*, length/width ratios were calculated.

Shrimp catch data, recorded by the National Partnership Enterprise (N.P.E), in Banjul, were used to calculate the percentages of the total catch in 1983 represented by the different shrimp fishery stations along the Gambia River.

RESULTS AND DISCUSSION

RIVER ZONES

Lower Estuary

Salinities in the lower estuary varied from 28.7 to 35.3 ppt. The bottom substrate in this part of the river was mainly composed of blue-gray mud, which in some places was mixed with fine plant debris or shell grit.

Table 1 summarizes the different taxa of benthic invertebrates found in the lower estuary of the Gambia River near Dog Island. Although all the listed invertebrates are marine, some require the estuarine environment to complete their life cycle. The sea urchin *Arbacia* made up the bulk of invertebrate biomass. Near the river banks this urchin was found mainly in the lower and bottom gill nets. In the main channel of the river, it occurred in varying amounts in the bottom trawl samples. The abundance of sea urchins in the lower estuary might be explained by their ability to feed on a wide range of food (algae, sessile invertebrates, animal remains). Moreover, it can be assumed that there was not much predation on the sea urchins, which are only eaten by fishes of the families Tetraontidae and Diodontidae (Cadenat 1954, Seret 1981).

TABLE 1. Invertebrate fauna of the lower estuary (Dog Island).

- ANNELIDA
  - Polychaeta
    - Errantia
      - Nereidae
        - *Nereis*
    - Sedentaria
      - *Spirographis spallanzani* (Viviani)
- ARTHROPODA
  - Crustacea
    - Malacostraca
      - Isopoda
        - Cymothoidae
          - *Nerocila*
      - Mysidacea
        - *Mysis*
      - Decapoda
        - Natantia
          - Penaeidea
            - *Penaeus duorarum* Burkenroad
            - *Parapenaeopsis atlantica* Balss
          - Caridea
            - *Exhippolysmata hastatoides* (Balss)
            - *Nematopalaemon hastatus* (Aurivilius)
            - *Palaemonetes*
        - Reptantia
        - Anomura
          - *Diogenes pugilator*
          - *Clibanarius africanus*
        - Brachyura
          - Xanthidae
            - *Menippe nodifrons* Stimpson
            - *Panopeus africanus* A. Milne Edwards
          - Portunidae
            - *Callinectes pallidus* (De Rochebrune)
            - *Callinectes marginatus* (A. Milne Edwards)
            - *Callinectes amnicola* (De Rochebrune)
      - Stomatopoda
        - *Squilla aculeata calmani* Holthuis
    - Cirripedia
      - Thoracica
        - *Chthamalus rhizophorae*
- CNIDARIA
  - Hydrozoa
    - Hydroida
      - *Sertularia*
  - Anthozoa
    - Octocorallia
- CTENOPHORA
- ECHINODERMATA
  - Ophiuroidea
    - Ophiurida
      - *Amphioplus congensis* (Studer)
  - Echinoidea
    - Arbacioida
      - *Arbacia*
  - Holothuroidea
    - Dendrochirota
      - *Cucumaria*
- MOLLUSCA
  - Scaphopoda
    - *Dentalium*
  - Gastropoda
    - Turitellidae
      - *Turitella*
    - Mesogastropoda
      - Cerithidae
        - *Tympanotonus fuscatus* (L.)
  - Bivalvia
    - *Anadara senilis* (L.)
    - *Tellina*
    - *Mactra nitida* Gmelin
    - *Pitar tumens* (Gmelin)
    - Anisomyaria
      - *Crassostrea gasar* (Dautz)
    - Taxodonta
      - *Arca gambiensis*
  - Cephalopoda
    - Decapoda
      - Sepioidea
        - *Lolliguncula mercatoris* Adam
        - *Sepia officinalis hierreda* Rang

The sea cucumber Cucumaria was captured in a seine along the river bank, where it occurred locally in high densities. This holothurid lives in an U-shape burrow and is a deposit and suspension feeder. The small violet brittlestar Amphioplus congensis and nereid worms were found in the mud from the Ponar samples. The free-living Polychaeta worms have omnivorous feeding habits and tend to live buried in the bottom substrate, where they are exposed to a relatively stable interstitial salinity (McLusky 1971).

With the exception of the oyster Crassostrea gasar, living on the roots of the mangrove vegetation along the river banks, mollusks were not especially abundant among the bottom fauna of the lower estuary. A general low abundance of mollusks in the lower course of the Gambia River was also mentioned by Monteillet and Plaziat (1980). The bivalve Anadara senilis, the West African bloody cockle, found near the river banks in the lower estuary, is tolerant of salinities as low as 8 ppt (Yoloye 1977). The cockle lives buried in the mud and is characteristic of muddy substrates, without vegetation, that emerge at low water during spring tide. It is extensively used as food along the coast of West Africa and mortar is made from the shells (Plaziat 1982, Fisher et al. 1981).

Two species of Cephalopoda were found in the trawl samples near Dog Island: Lolliguncula mercatoris, the Guinea thumb stall squid, a nearshore shallow water species limited to the west coast of Africa, and Sepia officinalis hierreda, the common cuttlefish. The few specimens of the latter, found in the lower estuary, were of small size (mantle length about 5 cm). Adult S. officinalis are found offshore, where they reproduce all year round. Squids eat fish and pelagic crustaceans, but cuttlefish feed along the bottom on benthic invertebrates, mainly shrimp and crabs (Barnes 1974).

The stomatopod Squilla aculeata calmani, the Guinean mantis shrimp, was caught occasionally in the trawls, as well as in the gill nets. It is a West-African species found along the coast and in estuaries from Senegal to Angola (Fisher et al. 1981).

The lumpy stone crab, Menippe nodifrons, was found only in the lower estuary, whereas the African mud crab, Panopeus africanus, occurred in the upper estuary as well. The first species is amphi-atlantic, and thus is found in the United States and Brazil. P. africanus, found from the south coast of Portugal to Angola, inhabits the tidal and subtidal zones of shallow coastal waters and estuaries, where it burrows in the mud.

According to Barnes (1974), the crabs of the family of Portunidae are the most powerful and agile swimmers among the Crustacea. This might explain their frequent occurrence, not only in the lower and bottom gill nets, but also in the upper nets. The big-fisted swim crab, Callinectes amnicola, was the most common crab species, both in the lower and upper estuary of the Gambia River. Callinectes pallidus, the gladiator swim crab, was also found as far upstream as Bai Tenda, whereas Callinectes marginatus, the marbled swim crab, was observed in limited numbers in the lower estuary. This crab is marine rather than estuarine. The ecology and distribution of Callinectes species is discussed in more detail in section III.

A variety of shrimp was caught near Dog Island including Penaeus duorarum, the pink shrimp, Parapenaeopsis atlantica, the Guinea shrimp, Nematopalaemon hastatus, the estuarine prawn, Exhippolysmata hastatoides, the companion shrimp, and Palaemonetes sp. The latter, a small specimen not yet identified to species, was very sparse in the main channel of the lower estuary, but was found in large quantities in the mangroves near Bai Tenda. Abundance, ecology, and

distribution of the most important shrimp species occurring in the Gambia River estuary are discussed in the section on commercially important invertebrates.

A parasitic isopod was frequently found attached to fishes captured in the estuary. It resembles *Nerocila* sp. (Cymothoidae) recorded by Trilles (1979) from fishes in Senegal.

Upper Estuary

During the annual floods in October, the salinities of the upper estuary were less than 1 ppt. As the floods declined, in December, salinities increased to 1-3 ppt. The rest of the year mesohaline salinities were measured, ranging from 9.9 to 14.5 ppt. As in the lower estuary, the bottom of the upper estuary consisted mainly of mud, but was richer in fine plant debris than the substrate near Dog Island.

Among the invertebrate bottom fauna of the upper estuary, listed in Table 2, some animals are marine, others brackish water inhabitants, and a few are freshwater species. A representative of the latter category is the small bivalve *Pisidium* (Sphaeriidae). Unlike most freshwater clams, which are abundant in the shallow parts of the river, the Sphaeriidae can be very numerous in the bottom substrate of deep waters. *Pisidium* was caught in benthic tows along the river banks in October and December (at a depth of about 3 m). It was also found in a dredge sample from the mangrove bolon near Bai Tenda, which was investigated in March 1984. The gastropod *Neritina adansoniana* was very abundant on the flood plain adjacent to this creek. In particular, it was found in the small streams (10 to 15 cm deep) that drained the flood plain during low tide. At low tide a salinity of 4 ppt was measured in these drainage channels, increasing to 11 ppt during the incoming tide. Monteillet and Plaziat (1980)

TABLE 2. Invertebrate bottom fauna of the upper estuary (Bai Tenda).

ANNELIDA
- Polychaeta
  - Errantia
    - Nereidae
      - *Nereis*

ARTHROPODA
- Crustacea
  - Isopoda
    - Cymothoidae
      - *Nerocila*
  - Amphipoda
  - Mysidacea
      - *Mysis*
  - Decapoda
    - Natantia
      - Caridea
        - *Crangon*
        - *Palaemonetes*
        - *Nematopalaemon hastatus* (Aurivilius)
      - Penaeidea
        - *Penaeus duorarum* Burkenroad
        - *Parapenaeopsis atlantica* Balss
    - Brachyura
      - Grapsidae
        - *Sesarma huzardi* Desmarest
        - *Sesarma elegans* Herklots
      - Xanthidae
        - *Panopeus africanus* A. Milne Edwards
      - Portunidae
        - *Callinectes amnicola* (De Rochebrune)
        - *Callinectes pallidus* (De Rochebrune)
- Insecta
  - Diptera
    - Nematocera
      - Chaoboridae

CNIDARIA
- Scyphozoa
  - Semaeostomae
      - *Aurelia aurita* (L.)

MOLLUSCA
- Bivalvia
    - Pisidiidae
      - *Pisidium*
  - Adapedonta
      - *Teredo*
  - Anisomyaria
      - *Crassostrea gasar* (Dautz)
- Gastropoda
  - Archaeogastropoda
    - Neritidae
      - *Neritina adansoniana* (Recl.)
  - Mesogastropoda
    - Cerithidae
      - *Tympanotonus fuscatus* (L.)

placed *Neritina* among the brackish water invertebrates that live only in habitats where salinity does not exceed 10 ppt.

Within the estuarine segment of the Gambia River, each small or large tributary (bolon) was bordered by a gallery of the mangrove, *Rhizophora* racemosa, which are surrounded by the mangrove, *Avicennia nitida* (Giglioni and Thornton 1965). The *Rhizophora* mangroves extend back from the river to the limit of normal daily tidal flooding. The *Avicennia* mangroves begin where the other species stop and extend back to the limit of extreme spring tides. The gastropod, *Tympanotonus fuscatus*, was very characteristic of the mangrove swamps. Densities of *T. fuscatus* exceeded 400 per m^2 on the barren mud flats (tans) that emerged at low tide on the bolon near Bai Tenda. Moreover, *T. fuscatus* was found on the muddy bottom of the bolon. In agreement with the findings of Plaziat (1977), who studied the polymorphism of this species in relation to environmental factors, *Tympanotonus fuscatus radula* occurred higher in the tidal zone than the "spiny" form *T. fuscatus fuscatus*. In the channel of the bolon the latter form was predominant, whereas *T. fuscatus radula* was most common on the mud flats and in the small drainage channels of the flood plain, coexisting with *Neritina*. *Tympanotonus fuscatus* tolerate salinities of 1 ppt or lower during the annual floods (Monteillet and Plaziat 1979). Both *Tympanotonus* and *Neritina* are herbivorous. Most of the dead wood in the mangroves was invaded by *Teredo*, the shipworm. Teredinidae play an important ecological role in the reduction of dead wood; they feed on the excavated sawdust. Because the shipworms appeared to tolerate freshwater conditions during at least 3½ months of the year, they may be able to survive for some time in freshwater reservoirs (Johnson 1978).

Oysters were abundant on the roots of the mangrove trees at the mouth of the bolons, while farther upstream in the creeks they disappeared completely. In their study on the mollusk fauna of the Gambia River, Monteillet and Plaziat (1979) classified the oyster, Crassostrea gasar, among the estuarine species that are able to tolerate a salinity of 1 ppt or lower during the rainy season.

In the larger and deeper drainage channels of the bolons, many Palaemonetes sp. were captured by means of a dip net, at a salinity of 5 ppt. During the day the shrimp were hiding in the bottom mud, but at night they were seen swimming in high numbers near the water surface. As observed in many crustaceans, the shrimp showed a vertical migration, being photopositive to reduced light intensities, thus moving toward the algal-rich surface waters for feeding at night, when exposure to predators is least. Some Palaemonetes also occurred in the small drainage channels of the flood plain, but in lower abundances than in the main channel of the creek. This species belongs to the freshwater genus Palaemonetes and is of small size, with a maximum total body length of 47 mm. Many ovigerous females were observed in March.

During low tide, in the daytime, the crab Sesarma huzardi was found on the flood plain. At night another marsh crab, Sesarma elegans, was captured on the emerged parts of the roots of mangrove trees in the bolon. The amphibious Grapsidae are characteristic of tidal swamps and mangroves, where they burrow in the mud. The african mud crab, Panopeus africanus, was found in a dredge sample from the bottom of the bolon.

Bottom trawl samples from the main river and benthic tows taken during October and December yielded very small shrimp, Crangon sp.; the maximum total length measured was 18 mm for a gravid female.

During the dry season *Callinectes* spp., primarily *Callinectes amnicola*, were abundant in the gill nets both in the river and in the bolons. Fish left overnight in the gill nets were partly eaten by the crabs. *Callinectes* is known to be extremely destructive, not only of the fish catches, but also of the nets (Reizer 1971, Durand and Skubich 1982). Baited crab traps left on the bottom near the river banks, during the day, contained over twenty crabs after a few hours.

Relatively few marine shrimp were caught in the trawls during March in the upper estuary. The catch consisted primarily of *Nematopalaemon hastatus*, including ovigerous females, a few *Parapenaeopsis atlantica*, and *Penaeus duorarum*.

Trawling in the main channel of the river yielded large amounts of medusae near Bai Tenda as well as further downstream at Tendaba. The jellyfish, *Aurelia aurita*, is known to invade estuaries, being tolerant of rather low salinities (Reid and Wood 1976). The mean salinity near Bai Tenda in March was 11 ppt. Toward the evening, the medusae were observed in high numbers near the water surface in the stretch of river between Bai Tenda and Tendaba. These jellyfish were not observed in the lower estuary. A possible explanation for the presence of a large jellyfish population in the upper estuarine reaches and its absence in the lower estuary is insufficient flushing of the upper estuary by the tides, at least during the dry season. If the water mass containing the *Aurelia aurita* population was trapped in the upper estuary, the jellyfish were trapped as well, for they depend on currents for their horizontal movements.

During the annual flood in October, Chaoboridae (Lakeflies) larvae occurred frequently in the benthos samples from the upper estuary. Lakefly larvae were not found in December and March, when the water was no longer fresh. The larvae

of Chaoboridae exhibit a pronounced diurnal migration, being confined to the bottom waters during the day and moving toward the surface layers at night. They prey on zooplankton, captured by means of their prehensile antennae. Lakefly larvae are very tolerant of low oxygen concentrations and can become abundant in the profundal zone of natural and man-made tropical lakes (Dejoux 1969, Petr 1969).

Lower River

Although tidal fluctuations were present in this part of the river, the water remained fresh throughout the year in the lower river zone. The bottom substrate, consisting mainly of mud, was covered with a considerable amount of dead leaves, branches, and other plant debris near the river banks.

Table 3 summarizes the invertebrate taxa found in the lower river zone. The presence of nereid Polychaeta in the bottom mud was an indication that the interstitial water was not completely fresh. A property of mud bottoms in estuaries is that the salinity is generally higher and more stable inside the substrate than in the overlaying water, thus allowing euryhaline marine species living within the mud to penetrate far upstream into the river (McLusky 1971).

Except for the Polychaeta, the bottom fauna of the lower river was composed of freshwater species. The overall abundance and the diversity of benthos were low in this stretch of the river. Trawling of the main channel did not yield any invertebrates. Mollusks, insect larvae and a freshwater shrimp were caught near the river bank, using a dredge.

The snail Bellamya unicolor, found near Bansang (310 km upstream) and in the upper river and headwaters of the Gambia River, was recorded by Monteillet and Plaziat (1979) to occur as far downstream as Wali Kunda (275 km upstream).

TABLE 3. Invertebrate bottom fauna of the lower river (Bansang).

- ANNELIDA
  - Polychaeta
    - Errantia
      - Nereidae
        - *Nereis*
- ARTHROPODA
  - Crustacea
    - Decapoda
      - Natantia
        - Caridea
          - *Potamalpheops monodi* (Sollaud)
  - Insecta
    - Odonata
      - Anisoptera
        - Corduliidae
    - Ephemeroptera
      - Polymitarcidae
        - *Povilla adusta* Navas
      - Baetidae
    - Trichoptera
      - Hydropsychidae
        - *Macronema*
    - Diptera
      - Nematocera
        - Chaoboridae
- MOLLUSCA
  - Bivalvia
    - Heterodonta
      - Corbiculidae
        - *Corbicula africana*
      - Sphaeriidae
        - *Pisidium*
  - Gastropoda
    - Mesogastropoda
      - Viviparidae
        - *Bellamya unicolor*

The clam Corbicula africana lives buried in the bottom substrate. It was found by Daget (1961) in the Gambia River in the Niokola Koba Park in eastern Senegal. This species, which is able to adapt to lake conditions, is very abundant in Lake Chad (Leveque 1967).

The freshwater shrimp Potamalpheops monodi occurred in a dredge sample taken in March along the river bank. The largest specimen collected was an ovigerous female with a total length of 14 mm. This shrimp is known to occur in the fresh waters of Senegal, Sierra Leone, and Cameroon and in the Niger delta (Durand and Leveque 1980), but has not been recorded from the Gambia River.

Dragonfly nymphs of the family Corduliidae were found among the plant debris near the river banks. The dead wood dredged from the bottom was inhabited by larvae of the caddisfly Macronema and by nymphs of the wood-boring mayfly Povilla adusta. The latter species is very abundant in Lake Chad (Dejoux 1969) and developed large populations in man-made lakes after river impoundment (Petr 1970a, McLachlan 1970). A description of the biology of the wood-boring mayfly is given by Corbet et al. (1974). As in the upper estuary, Chaoboridae larvae were found in the benthic tows from the lower river zone.

Upper River

Kekreti dam site -- Table 4 lists the benthic invertebrates that were found in the Gambia River at the site of the future Kekreti dam. Three different river habitats were sampled during the period of declining floods in December.

A sample was taken in slowly running water, 0.3 to 0.5 m deep, near the river bank. The bottom was muddy and covered with parts of dead trees and other plant debris. In this part of the river dragonfly nymphs belonging to the Gomphidae were predominant. They burrow in the bottom substrate and prefer a

TABLE 4. Invertebrate bottom fauna of the Kekreti dam site.

- ARTHROPODA
  - Insecta
    - Plecoptera
      - Perlidae
        - *Neoperla spio*
    - Ephemeroptera
      - Leptophlebiidae
        - *Adenophlebiodes*
        - *Fulletomimus*
      - Caenidae
        - *Caenodes*
      - Heptageniidae
        - *Afronurus*
        - *Notonurus*
      - Baetidae
      - Oligoneuriidae
        - *Elassoneuria*
      - Tricorythidae
        - *Dicercomyzon femorale* Demoulin
      - Polymitarcidae
        - *Povilla adusta* Navas
    - Trichoptera
      - Philopotamidae
        - *Chimarra*
      - Hydropsychidae
        - *Diplectronella*
      - Ecnomidae
    - Odonata
      - Coenagrionidae
        - *Pseudagrion*
      - Gomphidae
        - *Paragomphus*
- MOLLUSCA
  - Bivalvia
    - Schizodonta
      - Unionidae
        - *Caelatura mesafricana*
      - Mutelidae
        - *Aspatharia senegalensis* (Lea)
  - Gastropoda
    - Mesogastropoda
      - Viviparidae
        - *Bellamya unicolor*

slow current. Durand and Leveque (1980) mentioned that Gomphidae can become very abundant in the backwaters of streams and other temporary habitats. The mayfly nymphs Dicercomyzon femorale and Adenophlebiodes, found in similar habitats at Kekreti, require well-oxygenated waters without a strong current (Dejoux et al. 1981). The dead wood near the river bank offered a very suitable substrate for the nymphs of Povilla adusta, the wood-boring mayfly.

A second sample was taken farther away from the river bank, in moderately running water about 0.8 m deep, among stones and detritus overlying a rocky bottom. The most abundant invertebrates in this environment were Heptageniidae nymphs. Although these mayflies, with their flattened body shape, enlarged femurs, and laterally expanded gills, are well adapted to live on top of stones in the current, they seem to avoid the very fast running parts of streams (Petr 1970b). Nymphs of the damselflies Coenagrionidae, the second most abundant group in this habitat, are most frequently found in slowly running waters (Tachet et al. 1980). The nymphs of the Caenidae have no special adaptations for resisting a strong current, so they usually live in slowly to moderately running parts of the river.

Only one nymph of Neoperla spio was found in the samples from the Kekreti site. This stonefly, which is present in nearly all permanent streams of West Africa, prefers well-oxygenated and fast running habitats.

A third sample was collected toward the middle of the stream, at a depth of 0.5 m. The bottom consisted of stones, pebbles, and gravel and the current was moderate to strong. As in the previous habitat, Heptageniidae and Coenagrionidae nymphs were predominant. But, some caddisfly larvae were also found in this micro-environment. Although the Ecnomidae usually inhabit the quiet parts of streams, Hydropsychiidae, represented here by Diplectronella, prefer moderate

currents. The Philopotamidae larvae are characteristic of rapids, therefore almost entirely confined to streams in hilly and mountainous terrain. The snail *Bellamya unicolor* was also found near the middle of the river. Daget (1961) mentions that this snail is common in the Gambia River, often in high numbers under stones in rapids. *B. unicolor* appears well adapted to live in lakes, for it is widely distributed among the aquatic vegetation of Lake Chad (Leveque 1967) and Lake Turkana in Kenya (Beadle 1981). The clam *Caelatura mesafricana* is more common in streams than in lakes. In agreement with the data of Daget (1961), the mantle cavity of this bivalve harbors a mayfly nymph (Baetidae). Only empty shells of *Aspatharia senegalensis* were found.

The relative abundance of the different bottom invertebrates in the Gambia River near Kekreti is shown in Figure 2. The groups best represented, Ephemeroptera and Odonata, are characteristic of slowly to moderately running waters. Blackfly larvae (Simuliidae) were not found at the dam site in December, whereas at the sampling site in the Republic of Guinea they were very common during the same period.

Kedougou -- Table 5 shows the composition of the bottom fauna in the upper river zone near Kedougou. During the decline of the annual flood in December, five different river habitats were investigated. Water temperatures reached their annual nadir at 23.5°C during the December field trip. Additional benthos samples were taken in March, a period of low stream flows. The following micro-environments were sampled (Fig. 3):

Area A - A stagnant backwater, 0.1 to 0.2 m deep, with a bottom of cobble-stones covered with periphyton. The vegetation in the water, as well as on the dry parts of the river bed between the backwater and the main stream, consisted

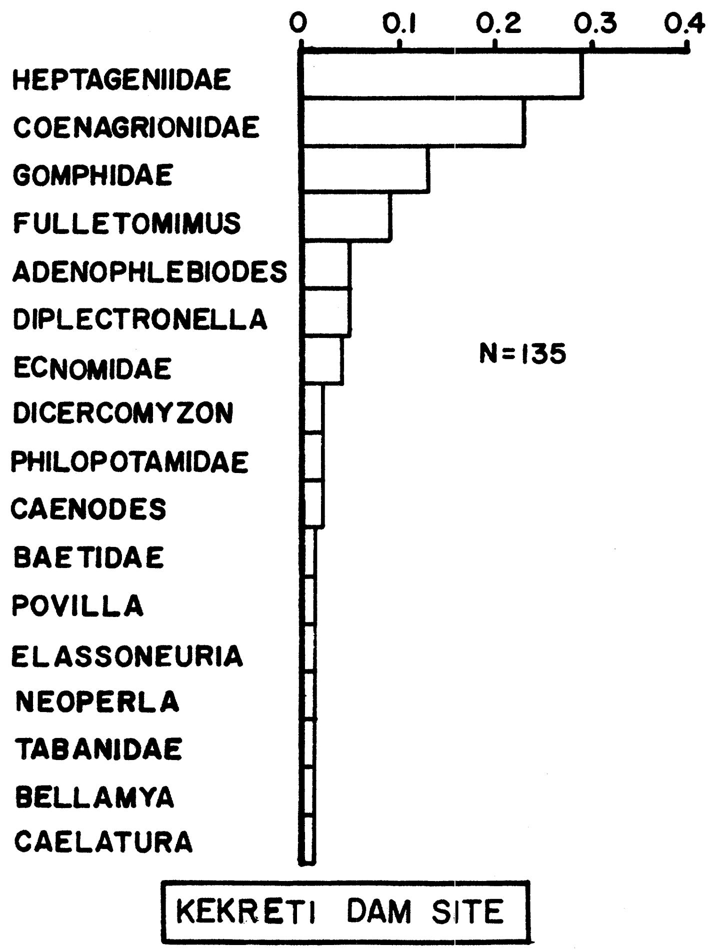


FIG. 2. Relative abundance (A) of benthic invertebrates of the Kekreti dam site during the declining floods.

TABLE 5. Invertebrate fauna of the upper river (Kedougou).

- ANNELIDA
  - Oligochaeta
    - Opisthopora
      - Lumbricidae
- ARTHROPODA
  - Insecta
    - Plecoptera
      - Perlidae
        - *Neoperla spio*
    - Ephemeroptera
      - Leptophlebiidae
        - *Thraulus*
        - *Adenophlebiodes*
        - *Fulletomimus*
      - Siphloneuridae
      - Caenidae
        - *Caenodes*
      - Heptageniidae
        - *Afronurus*
        - *Notonurus*
      - Baetidae
      - Oligoneuriidae
        - *Oligoneuriopsis*
      - Tricorythidae
        - *Machadorythus palanquin* Demoulin
        - *Dicercomyzon femorale* Demoulin
        - *Tricorythus*
    - Trichoptera
      - Leptoceridae
      - Philopotamidae
        - *Chimarra*
      - Hydropsychidae
      - Diplectronidae
        - *Diplectronella*
    - Diptera
      - Brachycera
        - Tabanidae
        - Rhagionidae
          - *Atherix*
      - Nematocera
        - Ceratopogonidae
          - "Vermiformes"
          - "Dasyhelea"
        - Simuliidae
          - *Simulium damnosum* (s.l.) Theobald
        - Limoniidae (= Tipulidae s.l.)
        - Chironomidae
          - Tanytarsini
          - Coryneurinae
          - Chironomini
          - Orthocladiinae
          - Tanypodinae
    - Odonata
      - Zygoptera
        - Coenagrionidae
          - Pseudagrion
      - Anisoptera
        - Corduliidae
        - Libellulidae
        - Gomphidae
          - *Paragomphus*
    - Hemiptera
      - Hydrocorisae
      - Naucoridae
      - Nepidae
        - *Ranatra*
    - Coleoptera
      - Elmidae
  - Crustacea
    - Decapoda
      - Brachyura
        - Potamidae
          - *Potamonautes ecorssei* Marchand
- MOLLUSCA
  - Gastropoda
    - Mesogastropoda
      - Viviparidae
        - *Bellamya unicolor*

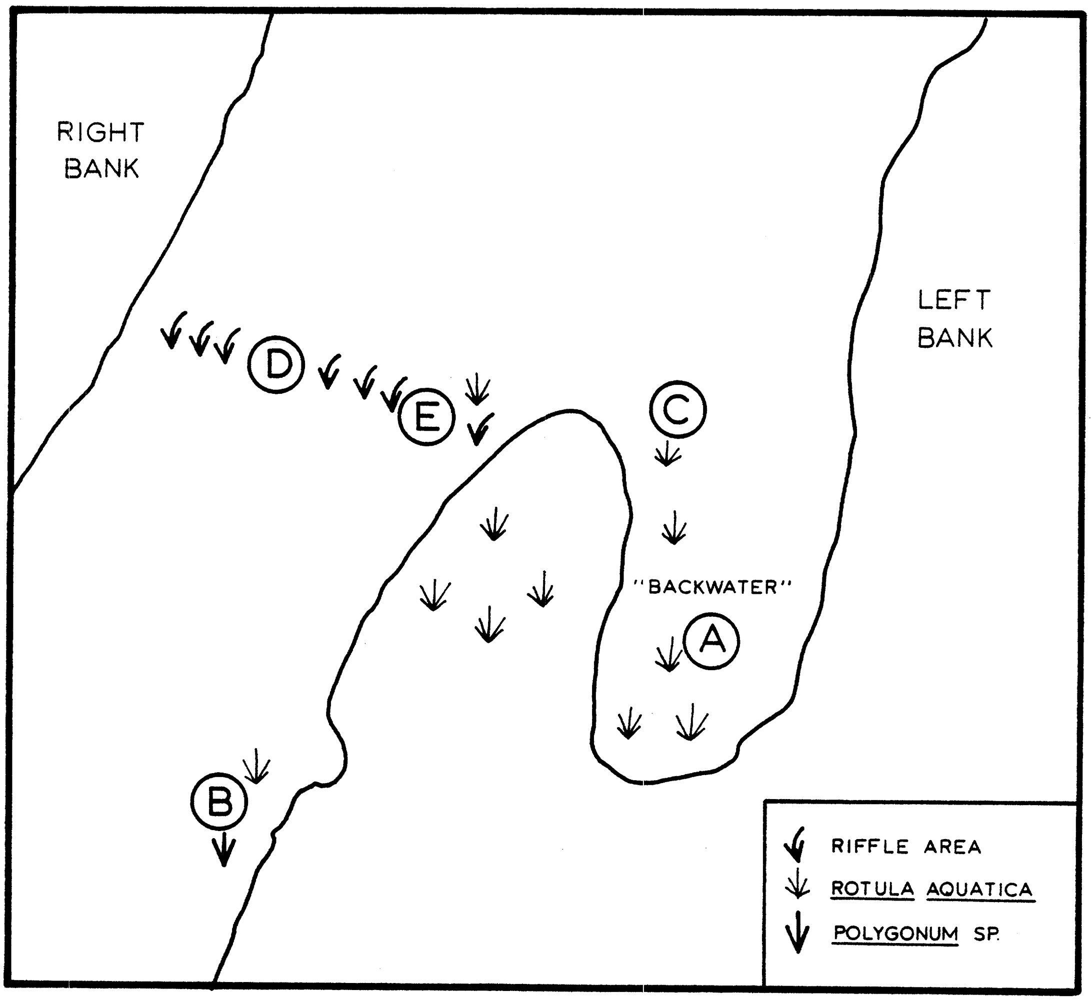


FIG. 3. Micro-environments sampled in the upper river zone near Kedougou.

of Rotula aquatica, a pantropical shrublike plant found in zones of the river that undergo important temporary inundation. During the floods, the plants were completely submerged and started to flower as soon as the superior branches emerged.

Area B - Stagnant to slowly running water, near the river bank, 0.2 to 0.3 m deep. The cobblestones of the bottom were covered with periphyton and plant debris. The vegetation was composed of R. aquatica and Polygonum.

Area C - Outlet of backwater (A) with a moderate current and a bottom composed of cobblestones, pebbles, and gravel.

Area D - Rapids near the middle of the river consisting of fast running water, 0.1 to 0.2 m deep, with a bottom substrate of stones and gravel. Macrophytes were not present in this part of the stream.

Area E - Riffle area with a very fast current, 0.1 to 0.2 m deep. The bottom consisted of stones and gravel. Dead leaves and other plant debris were trapped behind and underneath the stones. A few shrubs of Rotula aquatica grew in this area.

The relative abundance of the bottom invertebrates in the different habitats is shown in Figure 4. The mayfly nymphs of Adenophlebiodes, which are abundant in the backwater (A), require a well-oxygenated environment without strong currents and are well adapted to live underneath stones (Dejoux et al. 1981). Another mayfly, Thraulus, found in the stagnant to slowly running waters near Kedougou, was recorded by Dejoux et al. (1981) as characteristic of quiet waters. It has a well-developed gill system, adapted to low concentrations of dissolved oxygen. Petr (1970b), who studied the bottom fauna of the Black Volta River, observed an increase in abundance of Leptophlebiidae nymphs with decreasing current velocities. The mayfly Fulletomimus, found in the quiet

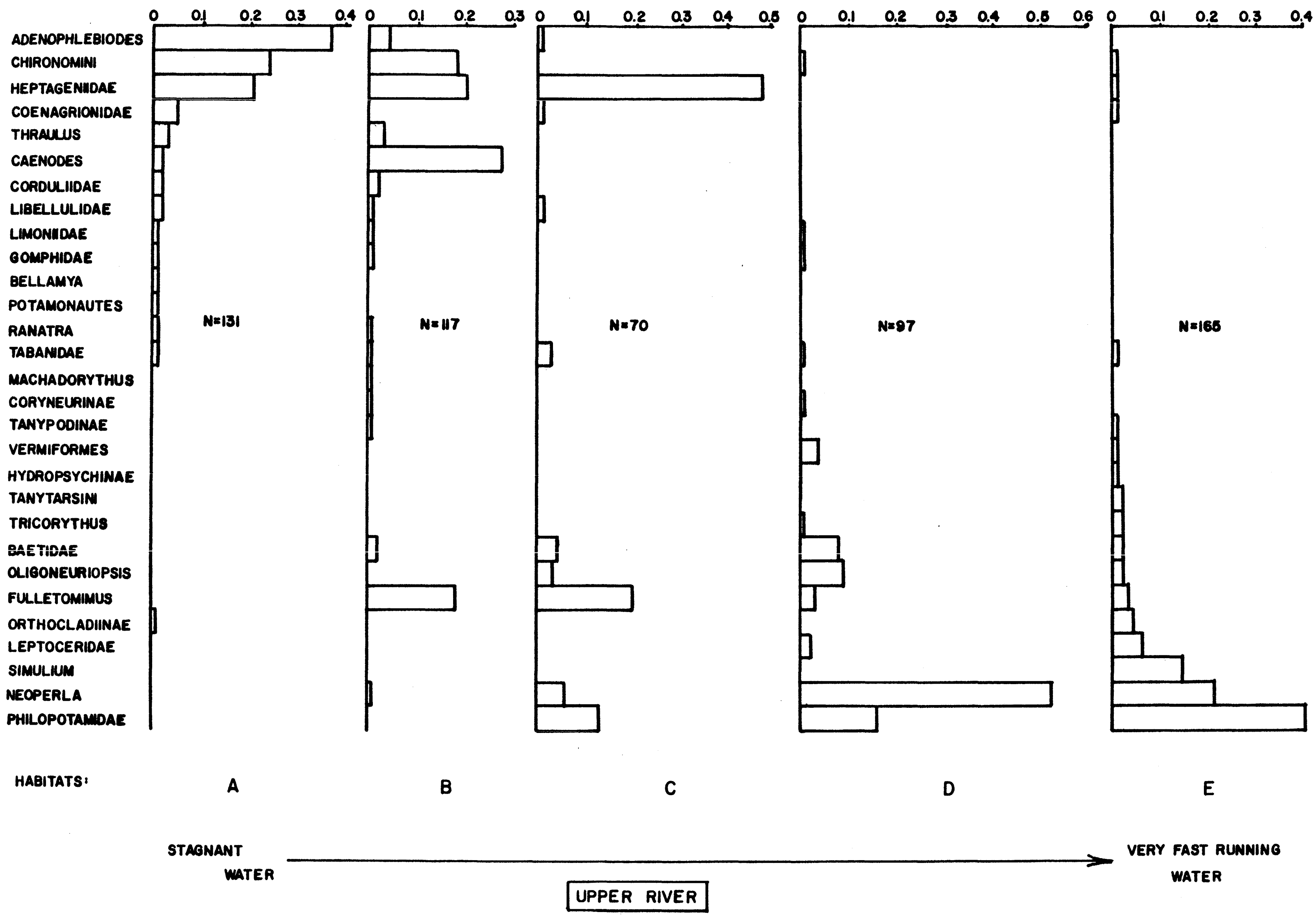


FIG. 4. Relative abundance of benthic invertebrates in different habitats of the upper river zone.

waters of the upper river, belongs to the same family. The nymphs of *Caenodes*, devoid of special adaptations to resist strong currents, prefer slowly running waters. Heptageniidae nymphs were more common in the moderate current of the outflow of the backwater in the main stream (C) than in the backwater itself (A). They are adapted to live on top of stones in the current.

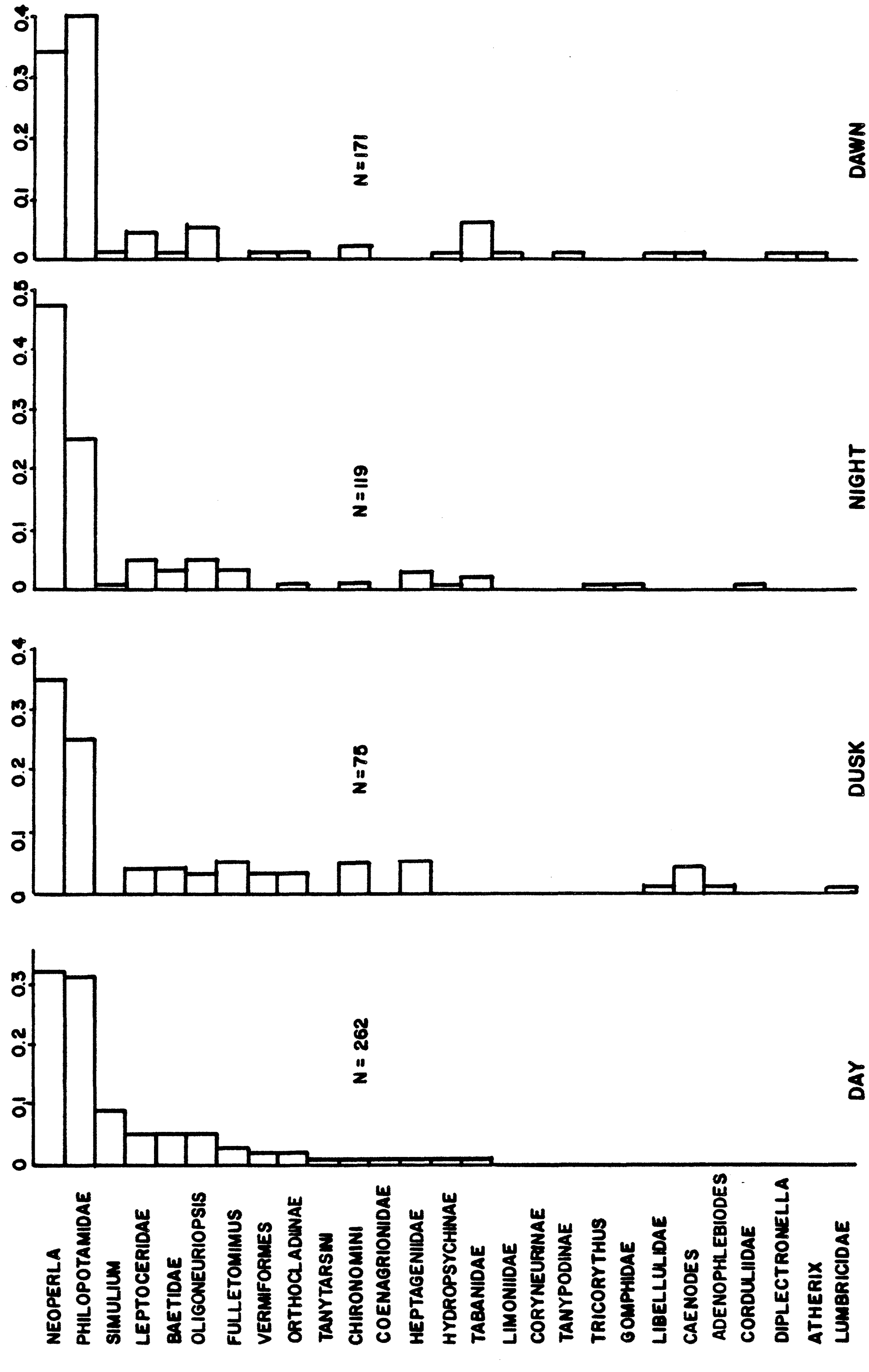
The larvae of Chironomini were most abundant in the stagnant backwater. They can become very numerous in lakes, even where there is a deficiency of oxygen. Odonata nymphs live mostly in calm waters and feed on chironomid larvae and other Diptera. They are natural enemies of malaria vectors. The lack of sandy substrate in the river at Kedougou might explain the low abundance of the burrowing Gomphidae nymphs. The Libellulidae and Corduliidae were also infrequent, due to the absence of suitable vegetation. The damselfly nymphs of the Coenagrionidae were well represented. These damselflies become very abundant in lakes (Dejoux 1969).

Most caddisfly larvae live in rapidly flowing water, but the case-dwelling Leptoceridae inhabit both streams and lakes. In agreement with the data of Dejoux et al. (1981), larvae of the Philopotamidae were found in the moderate to fast running parts of the river (C, D, and E), on a substrate of stones and gravel.

The stonefly *Neoperla spio*, characteristic of the fast running areas of rivers with stony bottoms, was particularly abundant in the rapids of the upper Gambia River (D and E). Blackfly larvae (*Simulium*) were found in this same type of habitat, mainly on the dead leaves trapped behind the stones of the riffle area. The larvae of the Orthocladiinae also inhabited the fast running parts of the stream. They require an environment rich in oxygen and are common in the Black Volta River on substrates exposed to strong currents (Petr 1970b).

No important shifts in the relative abundance of the invertebrate taxa were observed when comparing the samples collected at different times of the day in the rapids or stagnant water area (Fig. 5). Elouard and Leveque (1977) demonstrated the existence of a nocturnal rhythm in the drift of insect fauna and fish fauna in the rivers of the Ivory Coast, resulting from an increased activity of the animals after sunset. In the fast running parts of the Gambia River near Kedougou the free-living and agile nymphs of _Neoperla spio_ occurred in somewhat higher proportions at dusk and during the night (Fig. 5A). Furthermore, some invertebrates not found during the day in the rapids area appeared in the dusk samples, in particular nymphs of Caenodes, Adenophlebiodes, and Libellulidae. In the backwater area (Fig. 5B), Caenodes was significantly more abundant in the sample taken at sunset than during the day or night. The Heptageniidae seemed to be more active at night. Philopotamidae, not found during the day in the backwater, were collected in the night sample from this habitat. Adults of Elmidae occurred only in the night sample from the backwater.

Figure 6 shows the overall composition and relative abundance of benthos near Kedougou (day samples) during the period of declining floods. The predominant invertebrate groups are characteristic of moderately to fast running waters. Furthermore, the bottom fauna consisted almost exclusively of insects, i.e., a temporary fauna. Oligochaeta were practically absent, as was the snail _Bellamya unicolor_. Only one specimen of the freshwater crab _Potamonautes ecorssei_ was captured. Crabs were not found in the gill nets or trapped by seining, and thus assumed not very abundant in the upper river zone.



A. UPPER RIVER : "RAPIDS"

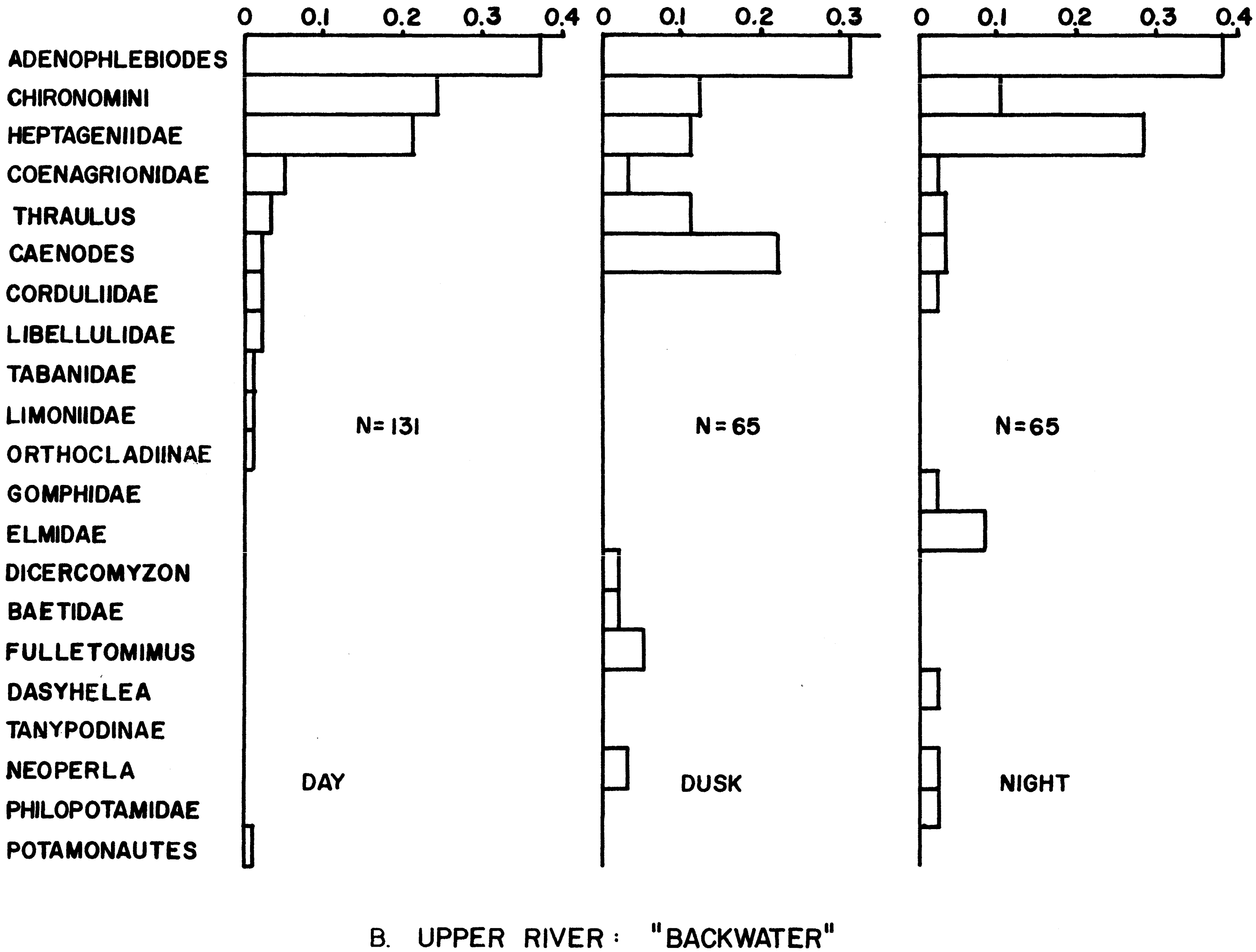


FIG. 5. Relative abundance of benthic invertebrates in samples collected at different times of the day in the rapids (A) and stagnant water area (B) of the upper river zone.

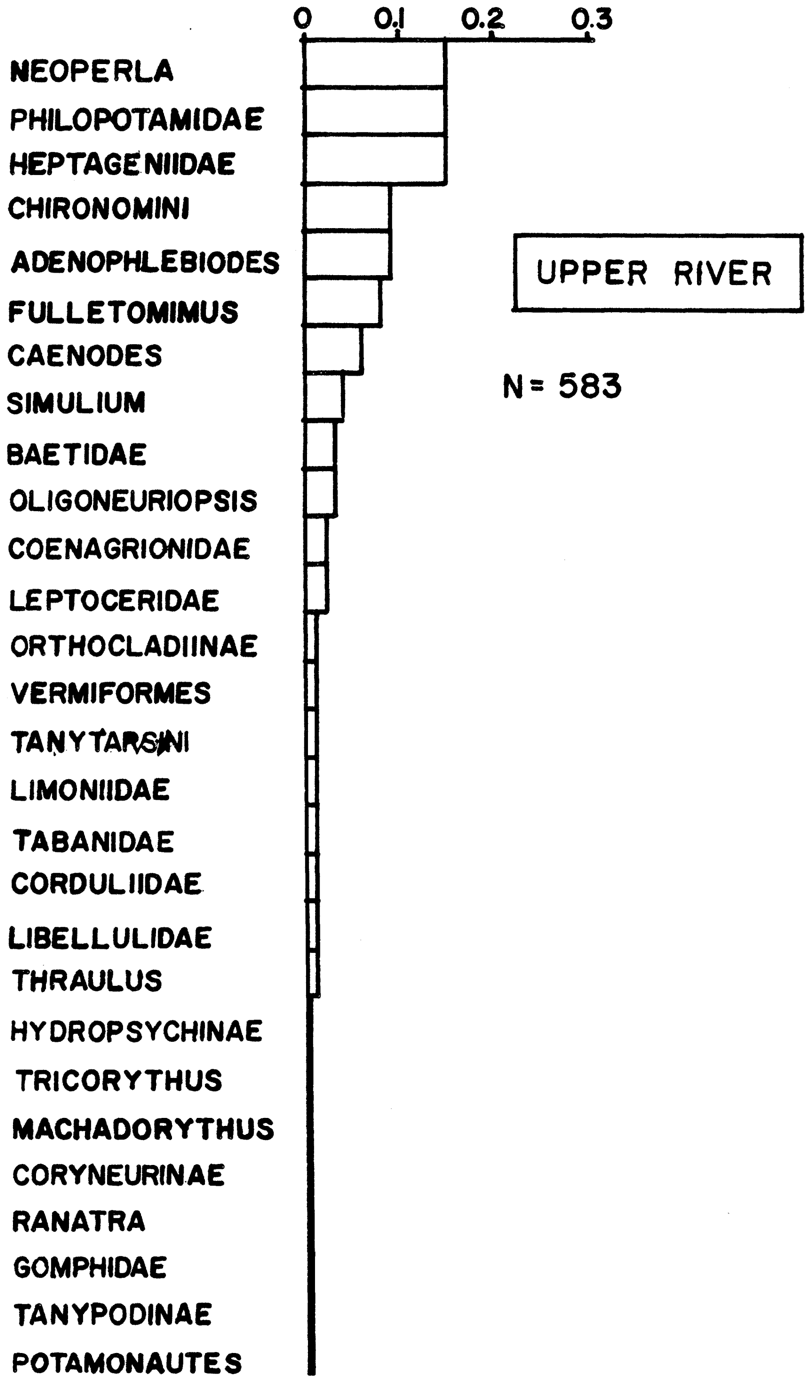


FIG. 6. Overall composition and relative abundance of the benthic invertebrates collected during the declining floods in the upper river zone.

Headwaters

The sampling site of the Gambia River headwaters in the Republic of Guinea (Fig. 7) is located within the area that will be flooded if the Kouya dam is constructed. The sampling site is approximately 6 km upstream from the confluence of the Gambia with the Litti. The surface area of the future lake will be 105 km^2. The Gambia River at this sampling site has fast running waters of rapids alternating with the slower current of the deeper areas. The river bed consists of stones and gravel overlying a rocky bottom, and in the slow running and stagnant parts of the river sand and mud cover the bedrock.

During the period of declining floods, in December, the water temperature was about 22°C. The semi-aquatic shrub *Rotula aquatica* was predominant in the shallow parts of the river and near the stony river bank. All of the stones in the riffle areas were covered with a small moss-like plant, *Tristicha trifaria* (Podostemaceae), characteristic of rapids and falls in tropical rivers. Some *Polygonum* occurred near the river bank, along with the sedge *Cyperus esculentus*. On the sandy parts of the river bank the vegetation consisted of the tall grasses *Vetiveria fulvibarbis* and *Digitaria gayana*.

Table 6 lists the bottom invertebrates from the sampling site in the Republic of Guinea. During the period of declining floods a variety of microenvironments within this stretch of the river was sampled. The following habitats were investigated:

Riffle area downstream from the bridge across the Gambia River connect the road from Balaki to Koubia (Fig. 7). This is very fast running water, 0.2 to 0.6 m deep. The bottom consisted of boulders, stones, and gravel. All the stones were overgrown with *Tristicha*, while dead leaves were trapped behind and underneath the stones. In the shallow water, some rooted vegetation was pres-

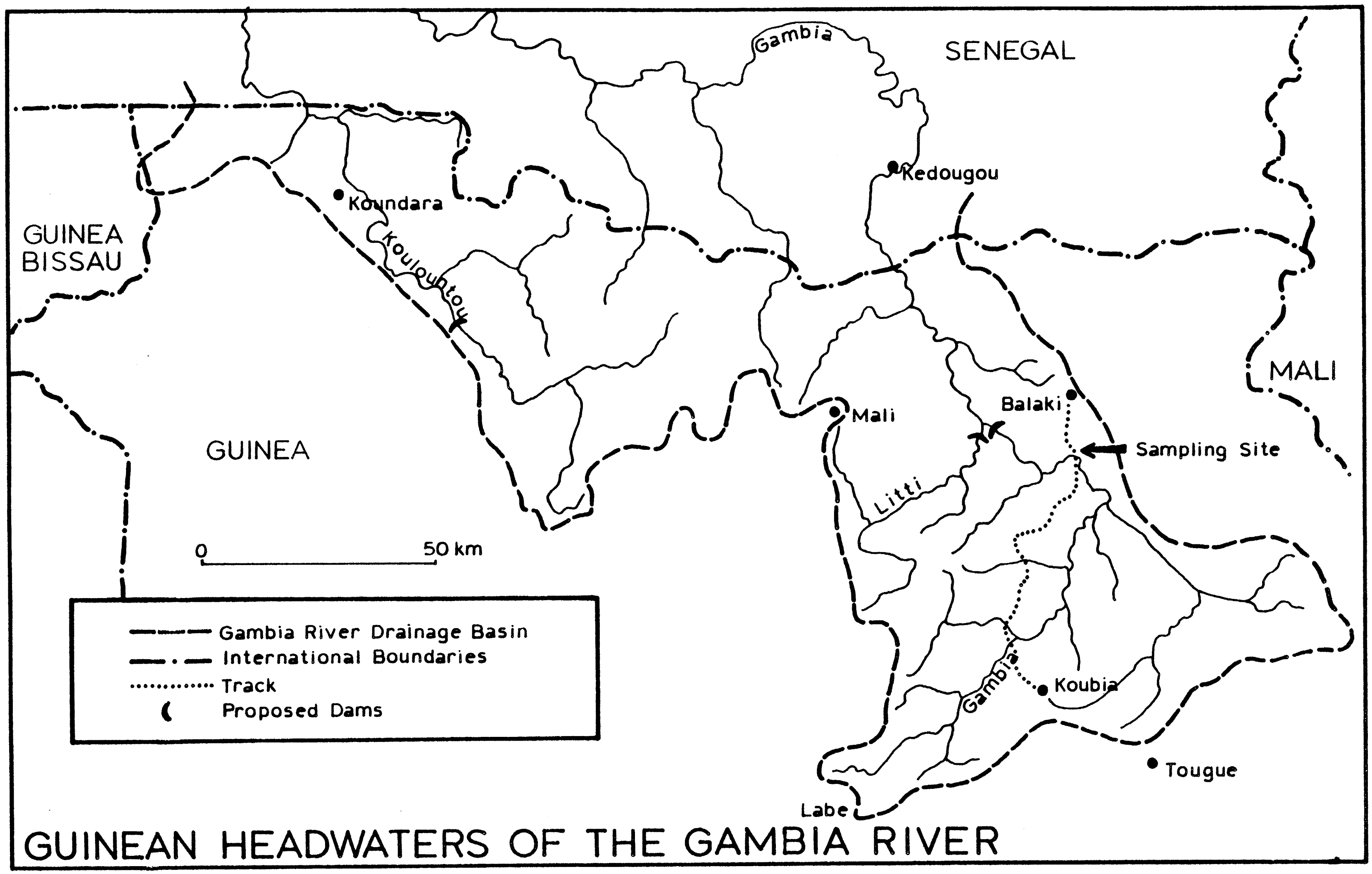


FIG. 7. Sampling site and proposed dam projects in the Guinean headwaters of the Gambia River.

TABLE 6. Invertebrate bottom fauna of the headwaters (Guinea).

- ANNELIDA
  - Oligochaeta
- ARTHROPODA
  - Insecta
    - Ephemeroptera
      - Leptophlebiidae
        - *Thraulus*
        - *Adenophlebiodes*
        - *Fulletomimus*
      - Caenidae
        - *Caenodes*
      - Baetidae
      - Heptageniidae
        - *Afronurus*
        - *Notonurus*
      - Oligoneuriidae
        - *Oligoneuriopsis*
      - Tricorythidae
        - *Tricorythus*
        - *Ephemerythus*
      - Ephemeridae
        - *Eatonica schoutedeni* (Navas)
    - Trichoptera
      - Hydropsychidae
        - *Macronema*
        - *Cheumatopsyche*
        - *Diplectronella*
      - Philopotamidae
        - *Chimarra*
      - Ecnomidae
      - Leptoceridae
      - Psychomiidae
      - Lepidostomatidae
      - Sericostomatidae
    - Plecoptera
      - Perlidae
        - *Neoperla spio*
    - Diptera
      - Brachycera
        - Tabanidae
        - Rhagionidae
          - *Atherix*
      - Nematocera
        - Empididae
        - Ceratopogonidae
          - "Vermiformes"
          - "Dasyhelea"

(continued)

TABLE 6. (continued).

Chironomidae
Tanypodinae
Chironominae
Chironomini
Orthocladiinae
Tanytarsini
Simuliidae
Simulium damnosum (s.l.) Theobald
Limoniidae (= Tipulidae s.l.)
Odonata
Zygoptera
Lestidae
Coenagrionidae
Pseudagrion
Anisoptera
Libellulidae
Gomphidae
Paragomphus
Corduliidae
Aeschnidae
Coleoptera
Elmidae
Potamophilis
Curculionidae
Hydrophilidae
Berosus
Dytiscidae
Noterinus
Hydroporus
Gyrinidae
Helodidae
Hemiptera
Hydrocorisae
Naucoridae
Naucoris
Geocorisae
Veliidae
Rhagovelia
Gerridae
Gerris
Trepobates
Crustacea
Decapoda
Brachyura
Potamidae
Potamonautes ecorssei
MOLLUSCA
Bivalvia
Schizodonta
Mutelidae
Aspatharia senegalensis (Lea)
Eupera parasitica

ent, primarily the sedge _Cyperus esculentus_. Figure 8 shows the relative abundance and composition of the benthos collected in this habitat. Stonefly nymphs, _Neoperla spio_, and blackfly larvae, _Simulium_, very characteristic of this kind of environment, were predominant. The Simuliidae were most abundant on the plants and dead leaves.

The fast running part of the river near the river bank, 0.1 to 0.3 m deep, has a bottom substrate of stones, gravel, and coarse sand. Rooted macrophytes were represented by _Polygonum_ and _Cyperus esculentus_, and _Tristicha trifaria_ covered the stones. Blackfly larvae were most abundant in this part of the river (Fig. 9). Shallow fast running water appears to offer a very suitable environment for breeding of the Simuliidae. The nymphs of the mayfly _Tricorythus_ were also abundant in this habitat. With their flattened body shape they are well adapted to cling to the substrate, thus resisting the strong currents. These ephemeropteran nymphs feed on periphytic algae (Petr 1970b). According to Dejoux et al. (1981), the following insect larvae are characteristic of a stony substrate covered with _Tristicha_: _Chimarra_ (Philopotamidae), _Cheumatopsyche_ (Hydropsychinae), Baetidae, and also the caterpillars of the Pyralidae and the larvae of Limoniidae and Rhagionidae. These larvae were found at the Guinea sampling site but in considerably lower abundance than the mayfly and blackfly larvae.

The slow running water near the river bank, 0.1 to 0.3 m deep, has a bottom substrate of stones, sand, and plant debris (leaves and branches). The mayfly _Caenodes_ dominated this habitat (Fig. 10). In the Black Volta River, Petr (1970b) found Caenidae nymphs with greater frequency at lower current velocities. The abundance of Gomphidae nymphs is in agreement with the data of Dejoux et al. (1981), who mentioned these burrowing dragonfly nymphs as

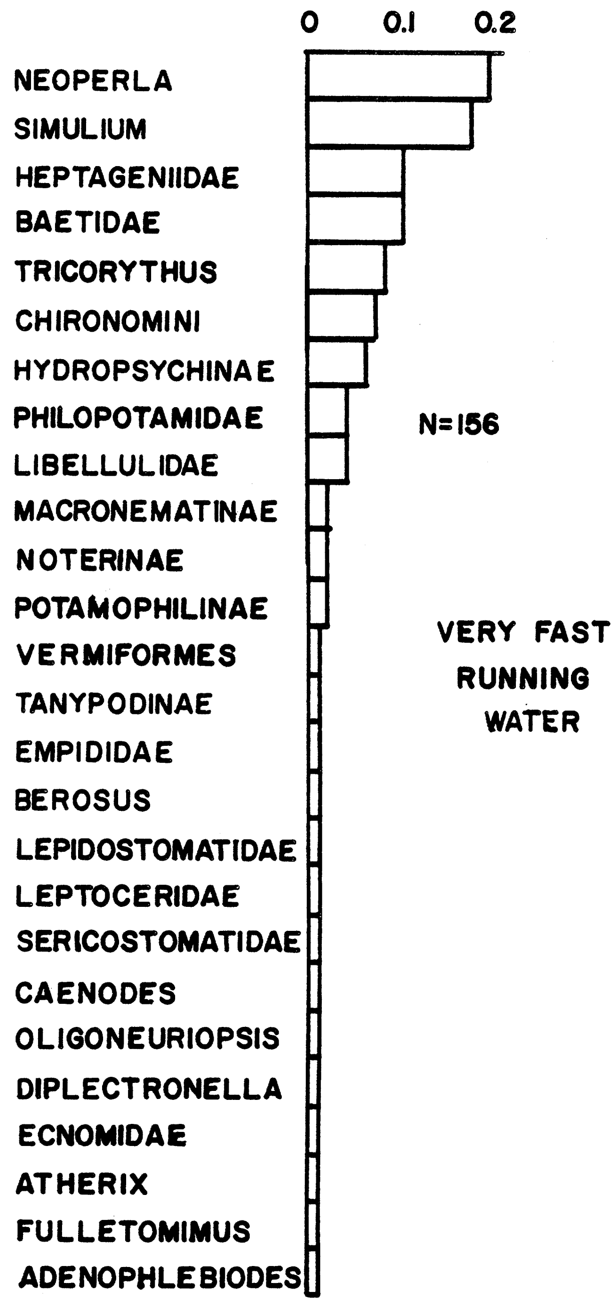


FIG. 8. Relative abundance and composition of benthos collected in a very fast running habitat of the Guinean headwaters.

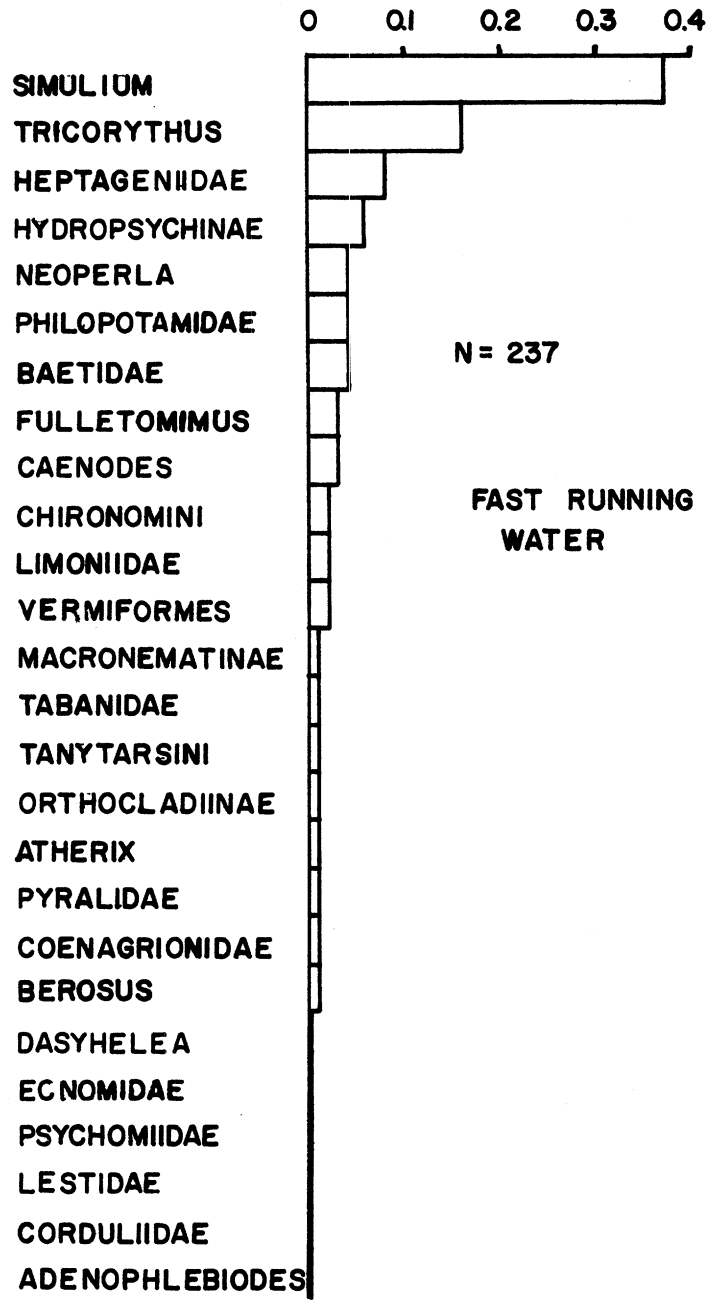


FIG. 9. Relative abundance and composition of benthos collected in a fast running habitat of the Guinean headwaters.

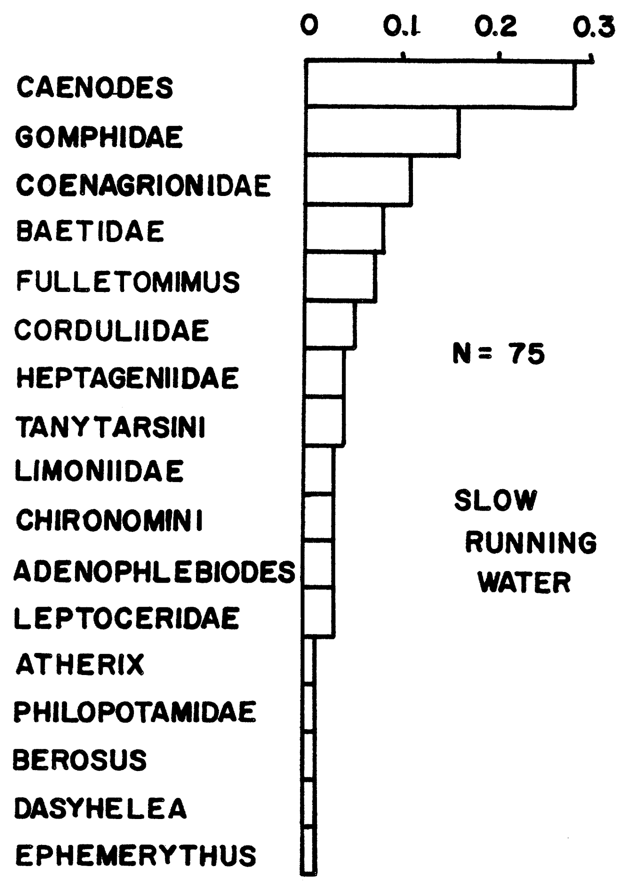


FIG. 10. Relative abundance and composition of benthos collected in a slowly running habitat of the Guinean headwaters.

characteristic of slow running waters with a sandy substrate. The nymphs of the Coenagrionidae show a preference for this kind of environment as well. Dejoux (1969) found this group of damselflies very abundant among the vegetation of Lake Chad. Among the less abundant taxa, the case-dwelling larvae of the Leptoceridae are also found in both streams and lakes.

The very slow running water which exists near the river bank has vegetation consisting of the grass *Vetiveria fulvibarbis*. The bottom consists of stones, gravel, sand, and some dead wood. Adult Potamophilinae, belonging to the beetle family of Elmidae, characteristic of streams, were dominant in this part of the river (Fig. 11), as was an adult snout beetle. The Curculionidae are mainly terrestrial, but some insects crawl down plants growing in the water to feed and oviposit. Waterbugs (Heteroptera), represented by *Naucoris* in this river habitat, are characteristic of quiet waters. The burrowing nymphs of *Eatonica schoutedeni* were extremely rare in this habitat. These nymphs are more commonly found in lakes (Dejoux 1969).

Backwater and stagnant water, 0.2 to 0.8 deep, with a bottom substrate consisting of sand, mud, and plant debris. Similar to the backwater near Kedougou (Fig. 4), nymphs of *Adenophlebiodes* were dominant in this type of habitat in the Republic of Guinea, as were *Caenodes* and *Thraulus* (Fig. 12). Waterbugs (Heteroptera) were represented by adults of Gerrinae, Trepobatinae, and Rhagoveliinae, all semi-aquatic and characteristic of stagnant waters. Because the waterbugs stride rapidly over the water surface, they were difficult to catch. Therefore, it can be assumed that the Heteroptera were more abundant than was reflected by the samples (Fig. 12). Although mainly a terrestrial group, the immature stages of some species of Tabanidae are truly aquatic. The eggs are laid on foliage, rocks, or sticks just above the water surface, and

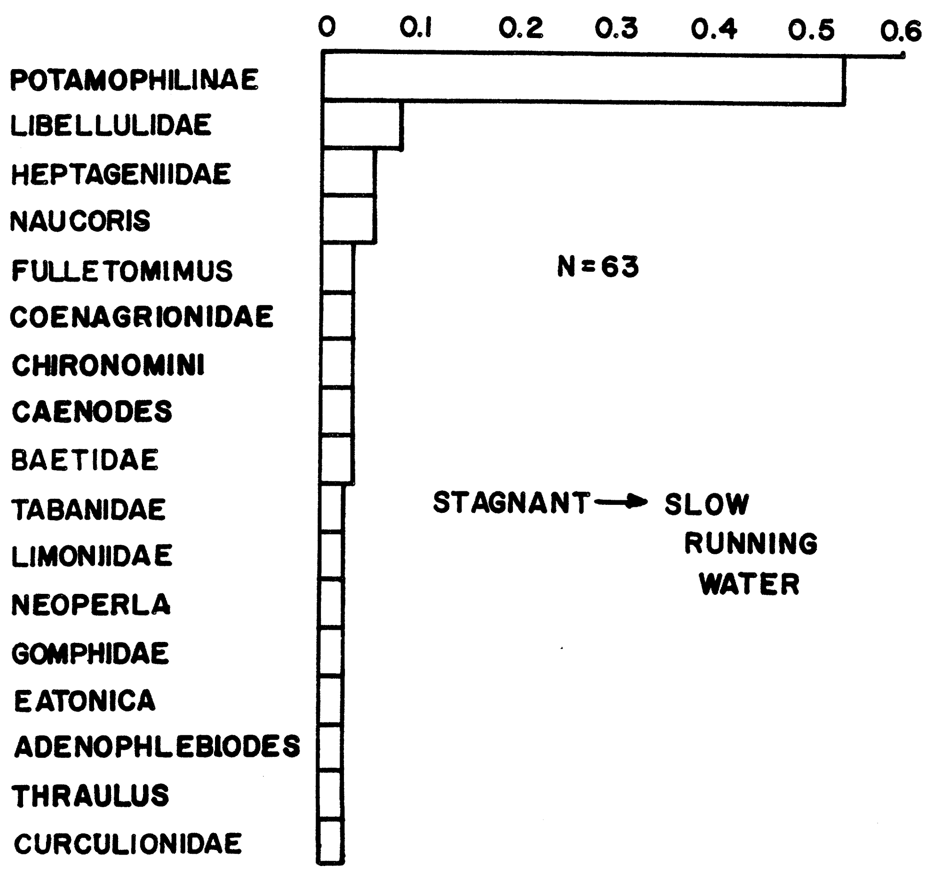


FIG. 11. Relative abundance and composition of benthos collected in slowly running to stagnant water of the Guinean headwaters.

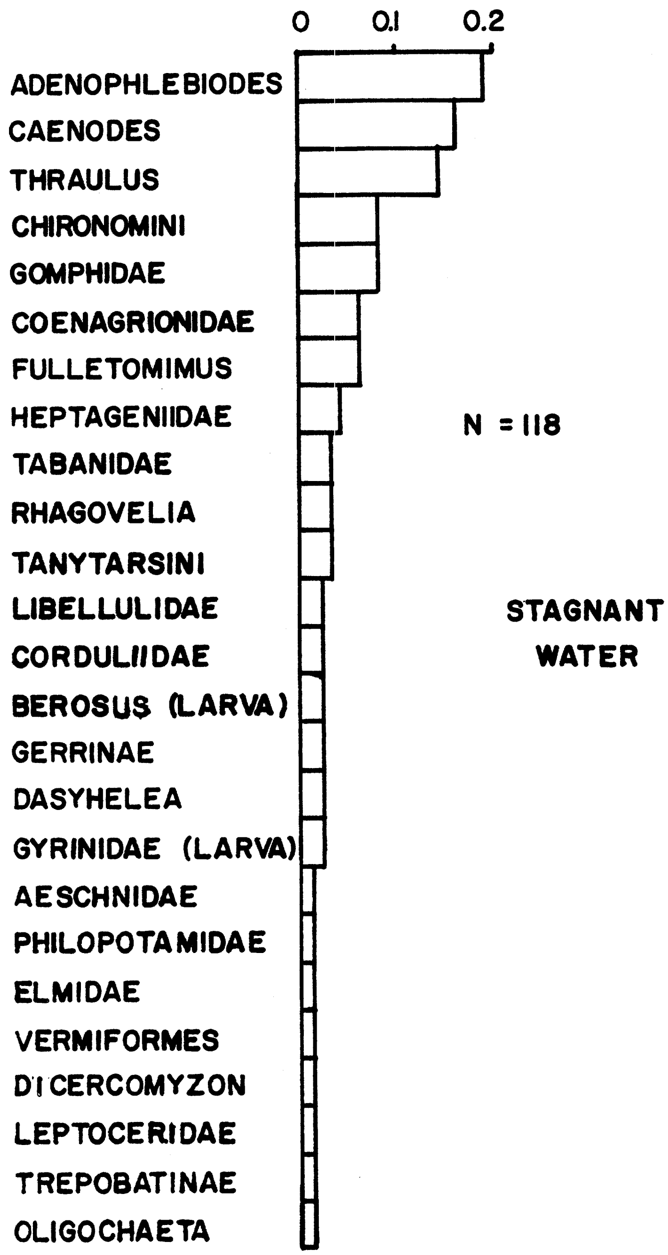


FIG. 12. Relative abundance and composition of benthos in a stagnant water area of the Guinean headwaters.

when the larvae hatch they fall into the water. Dragonfly nymphs of four different families were found: Gomphidae, Libellulidae, Corduliidae, and Aeschnidae. They prefer quiet waters with a substrate of sand or mud and plant debris. All odonate nymphs are carnivorous.

Abundance of the invertebrates representing the permanent aquatic fauna was very low in the headwaters zone. Among the specimens collected were a crab Potamonautes ecorssei, some oligochaets, and two clams, Aspatharia senegalensis and Eupera parasitica. Both species of clams have been recorded from the Gambia River in the Niokola Koba Park by Daget (1961); the first species is characteristic of streams, while the latter occurs also in lakes (Leveque 1967).

The bottom fauna in the headwaters of the Gambia River was characterized by a high taxonomic diversity, resulting from the large variety of micro-environments in this zone. With respect to the total number of benthic invertebrates collected during December, the larvae of Simuliidae, blackflies, were by far the most abundant, followed by the nymphs of Tricorythus and Caenidae. Somewhat less abundant, but still numerous, were the Heptageniidae and the larvae of the stonefly Neoperla spio. The overall abundance of benthos was rather low during December, when the bottom invertebrates started to recolonize the river bed at the end of the annual flood. In general, abundance and biomass of the benthos increased during the course of the dry season. In the Bandama River (Ivory Coast) Leveque et al. (1983) observed the highest densities in the main insect groups (Ephemeroptera, Trichoptera, Simuliidae, and Chironomidae) during the low water period on the stony substrates, covered with Tristicha trifaria. Toward the end of the dry season, when stream flows decrease, stagnant pools develop which benefit those invertebrates that are tolerant of low oxygen concentrations, such as mosquito larvae and the aquatic snails Biomphalaria and Bulinus.

Petr (1970b) has shown that the bottom fauna of the riverine pools, flats, and backwaters was the source of aquatic invertebrates for newly created lakes following river impoundment; many of the species found in these kinds of river habitats were pre-adapted for life in a lake environment.

COMPARISON OF RIVER ZONES

Minimum, maximum, and mean values of temperatures, dissolved oxygen concentrations, and salinities for the lower and upper estuary of the Gambia River are shown in Figure 13. These data are presented for the most important stages in the flow regime of the river (rising waters in July, floods in October, declining waters in December, and low water in March). Salinity in the upper reaches of the estuary varied over a much wider range than near the river mouth at Dog Island. During the annual flood in October, the water was fresh near Bai Tenda. The water temperature in the lower estuary was lowest in December, when the seawater was coldest. The upper estuary, during this same period, had a temperature similar to that of the lower river. Temperatures attained their annual minimum in February-March, when the river water near Bai Tenda became mixed with seawater.

The occurrence of marine benthic invertebrates in the different zones of the Gambia River is shown in Figures 14-17. The distribution of the macro-invertebrates composing the benthic fauna of the fresh waters of the Gambia River is presented in Figures 18-24.

Near Dog Island in the lower estuary, all benthic invertebrates collected were marine species. In the upper estuary, an area of large seasonal salinity fluctuations, only a restricted number of marine animals persist. Echinoderms, which were very abundant near the river mouth, decreased rapidly in number at

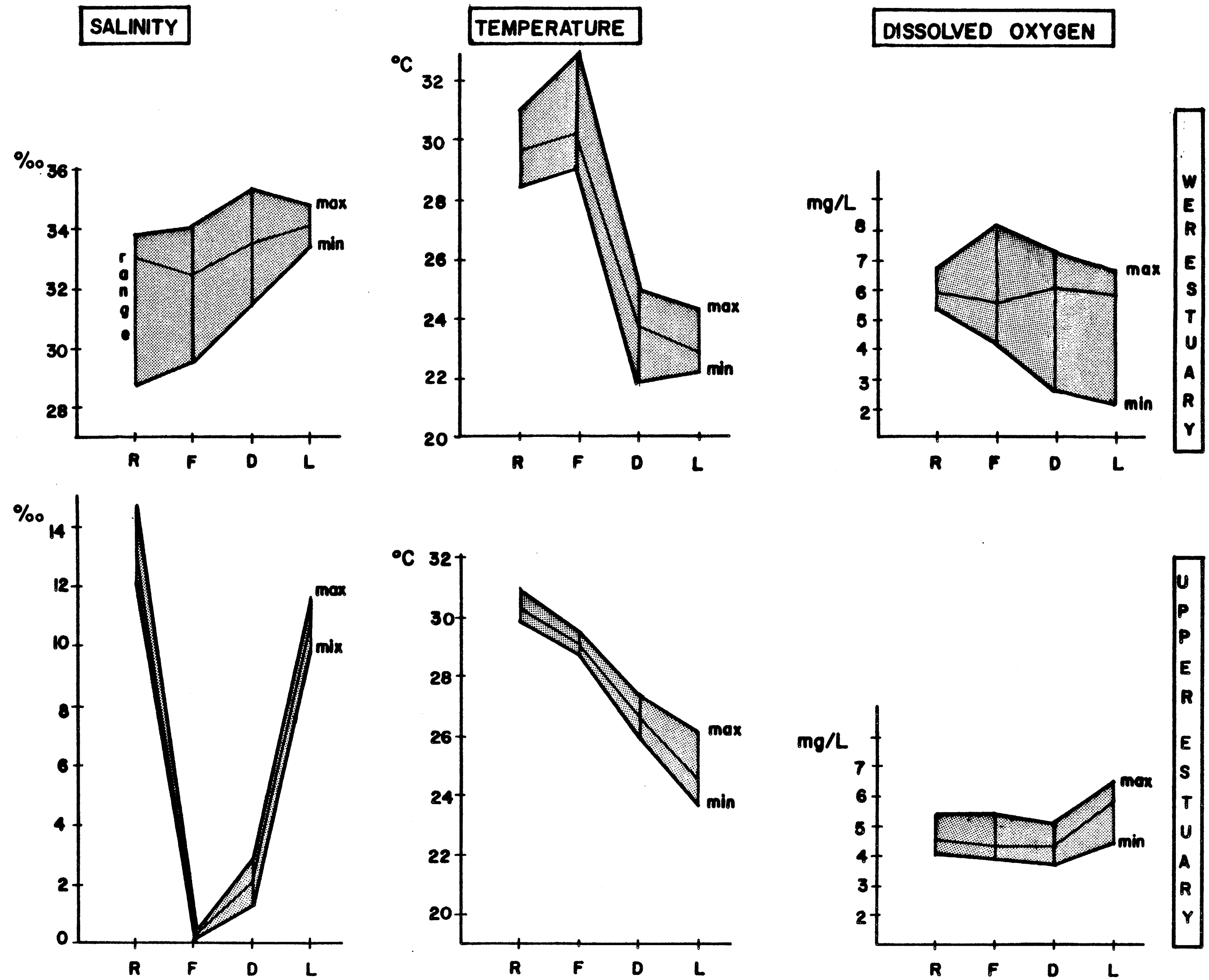


FIG. 13. Minimum, maximum, and mean temperatures, oxygen concentrations, and salinities in the lower and upper estuaries of the Gambia River during different hydrological periods.

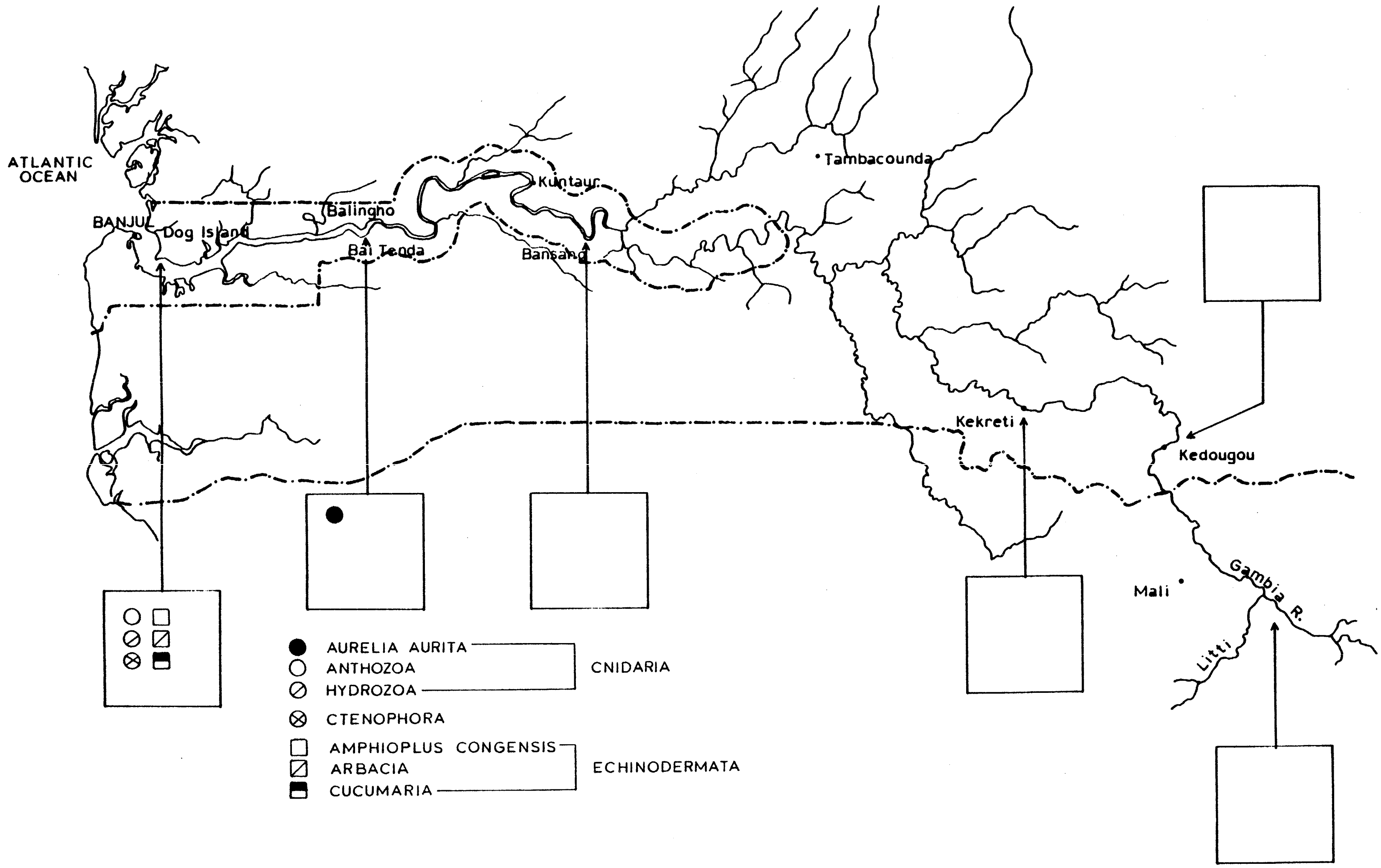


FIG. 14. The occurence of Cnidaria, Ctenophora, and Echinodermata in the Gambia River.

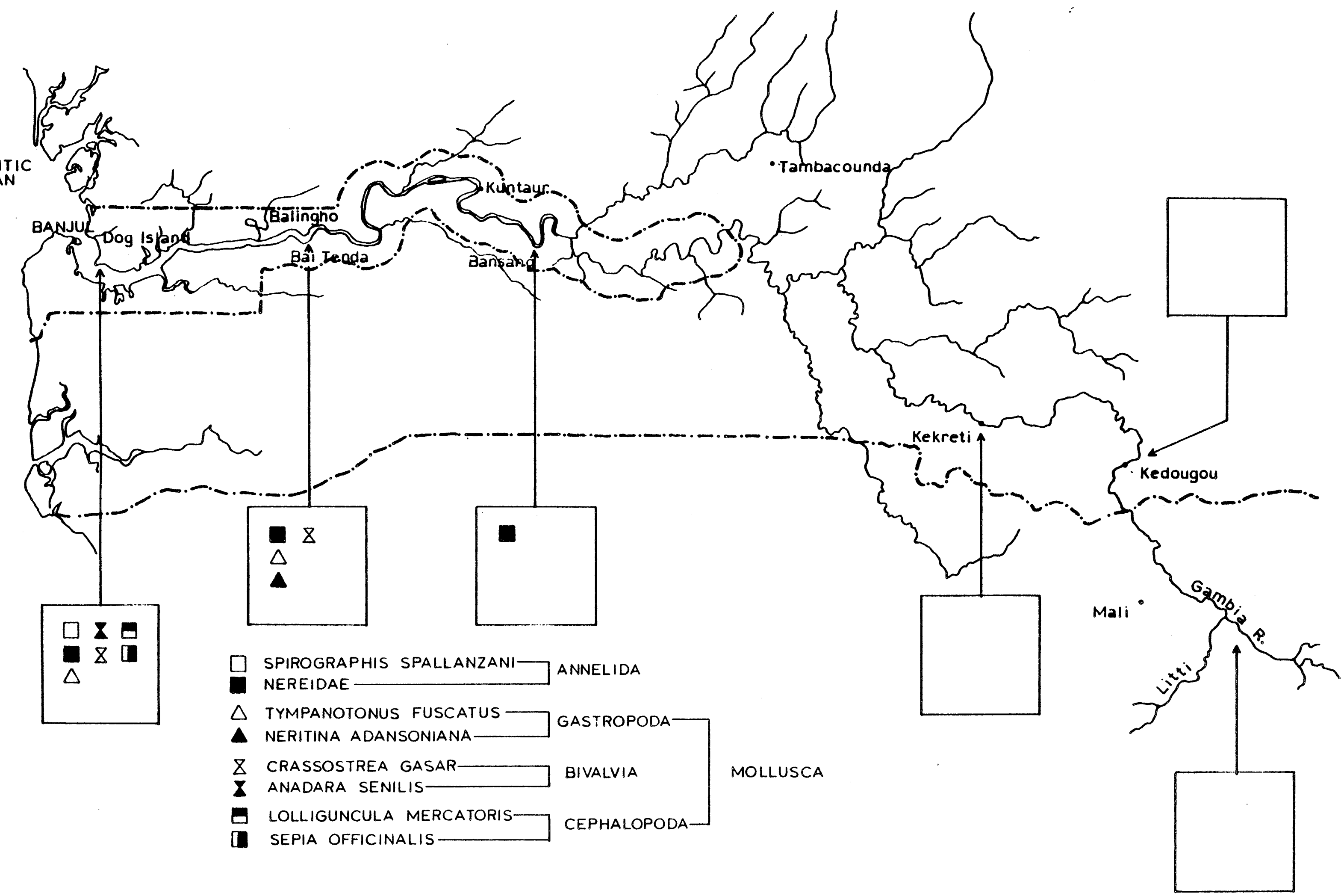


FIG. 15. The occurrence of marine Annelida and Mollusca in the Gambia River.

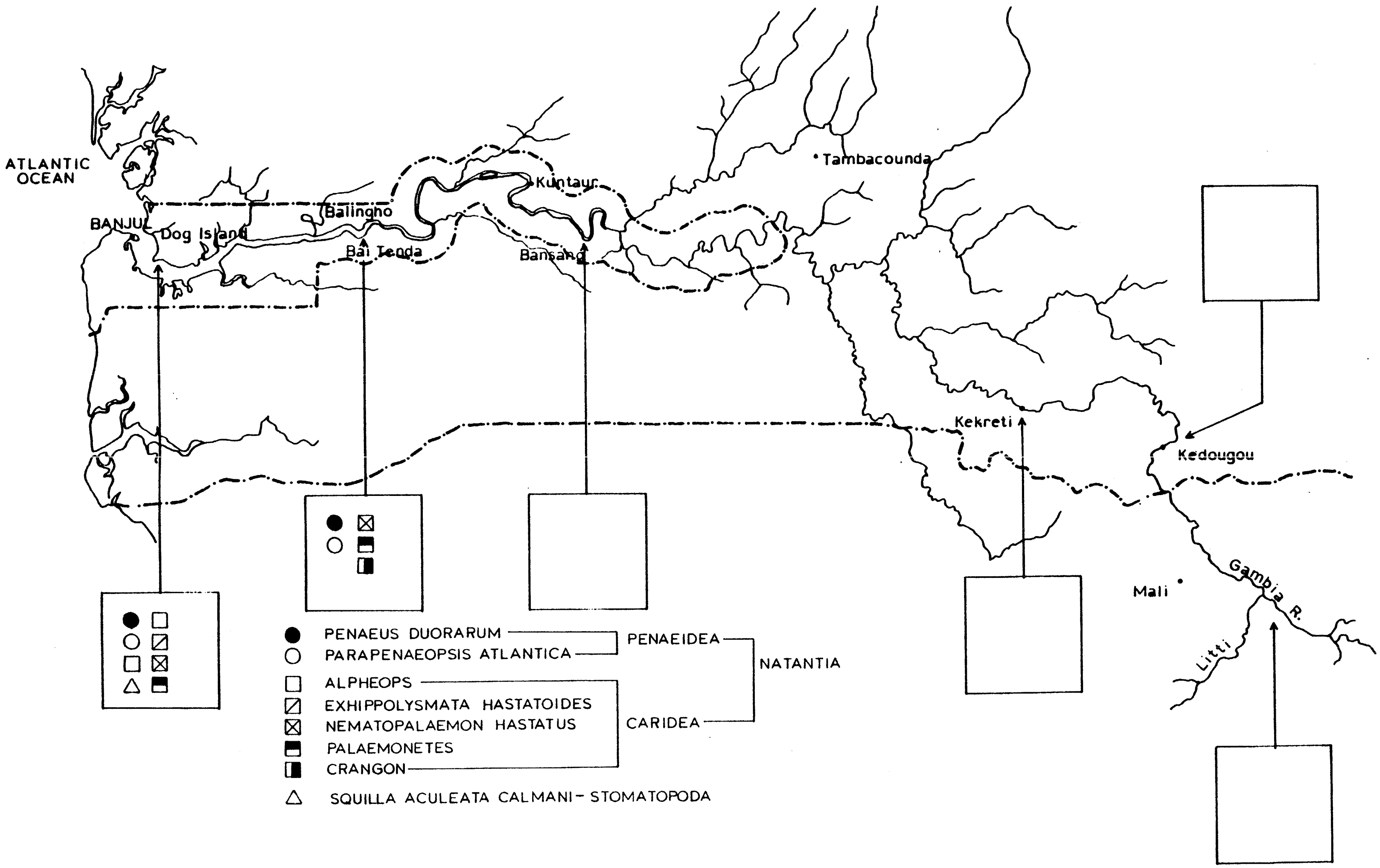


FIG. 16. The occurrence of marine Natantia and Stomatopoda (Crustacea) in the Gambia River.

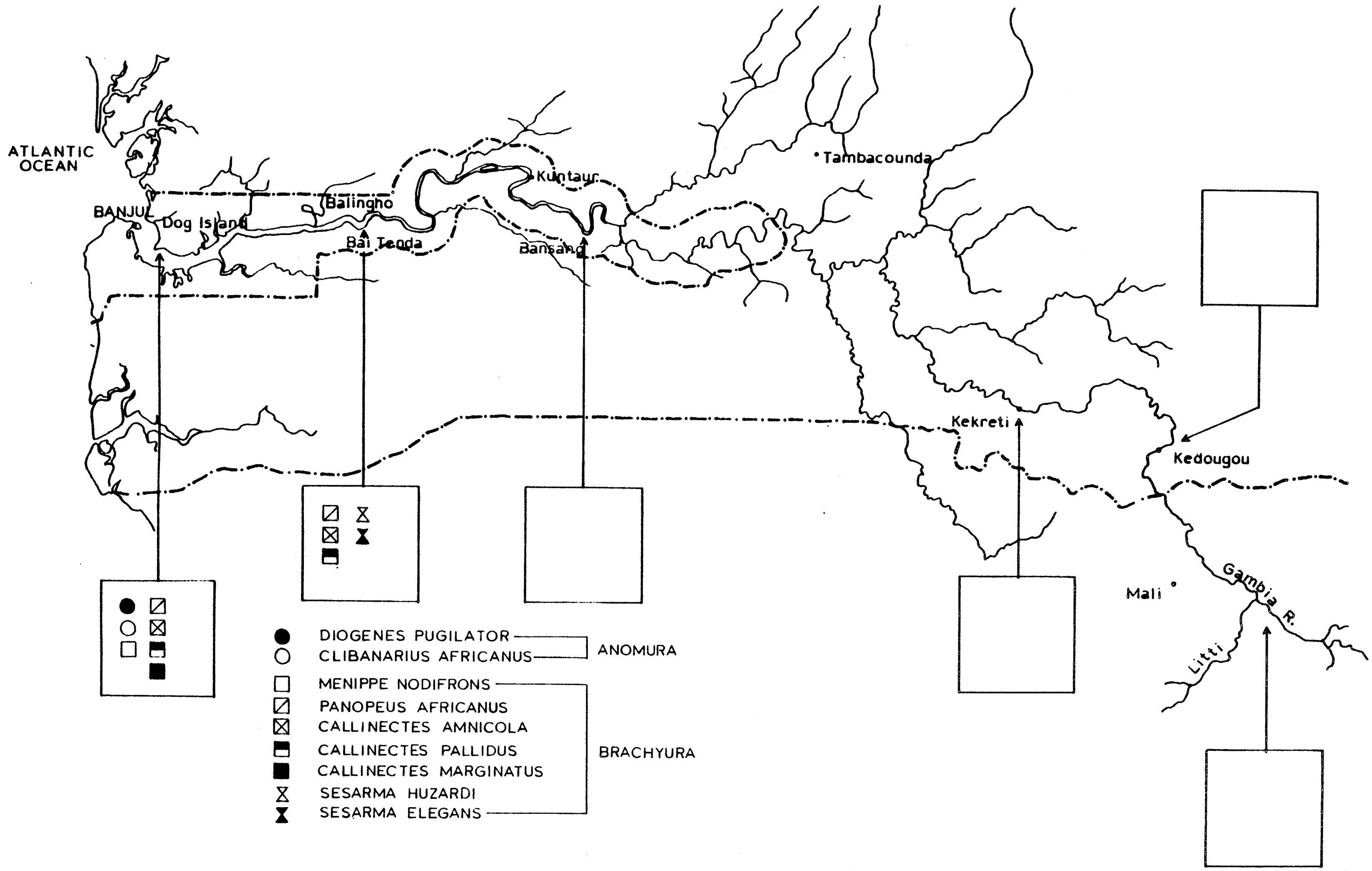


FIG. 17. The occurrence of Anomura and marine Brachyura (Crustacea) in the Gambia River.

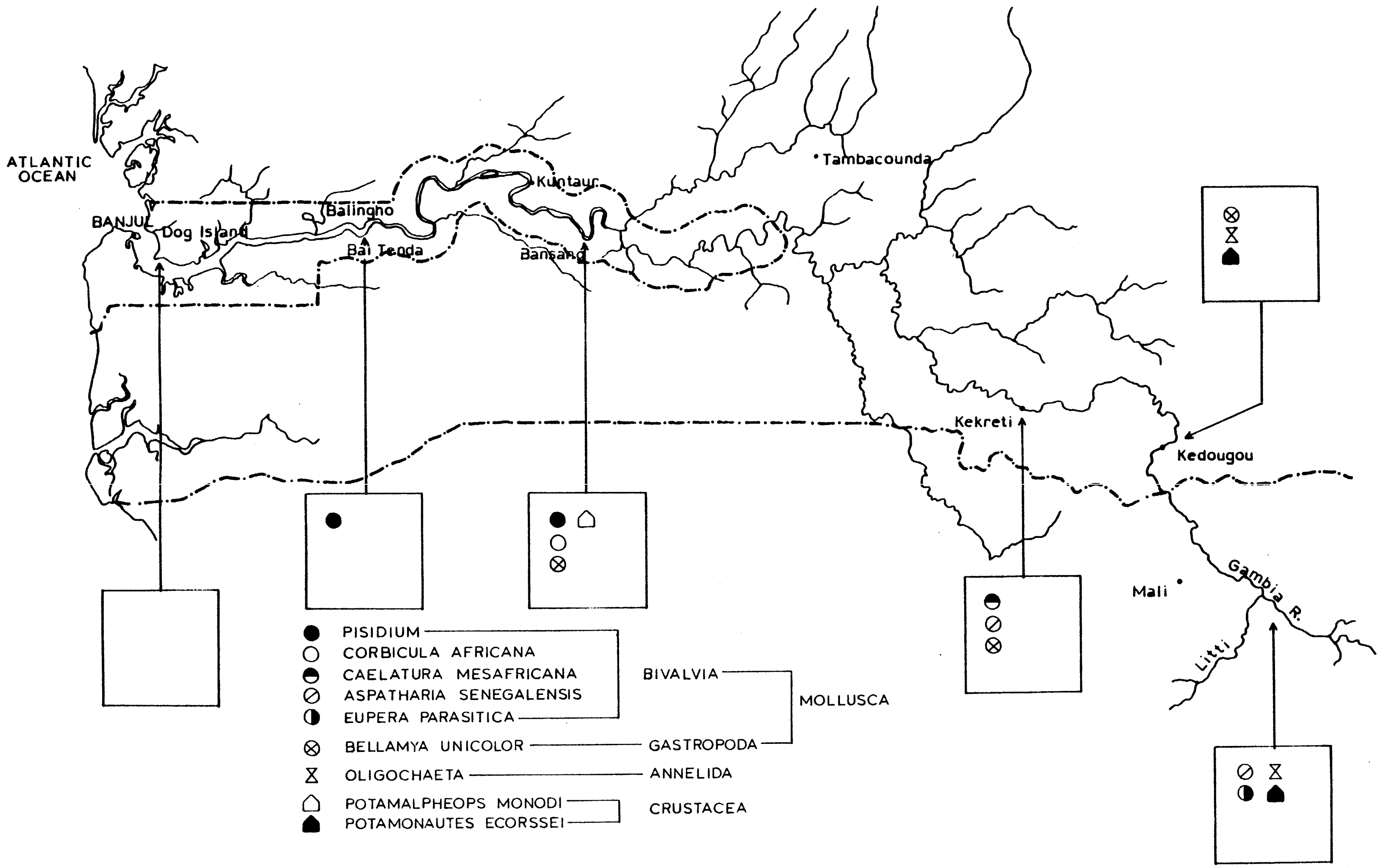


FIG. 18. The occurrence of freshwater Mollusca, Annelida, and Crustacea in the Gambia River.

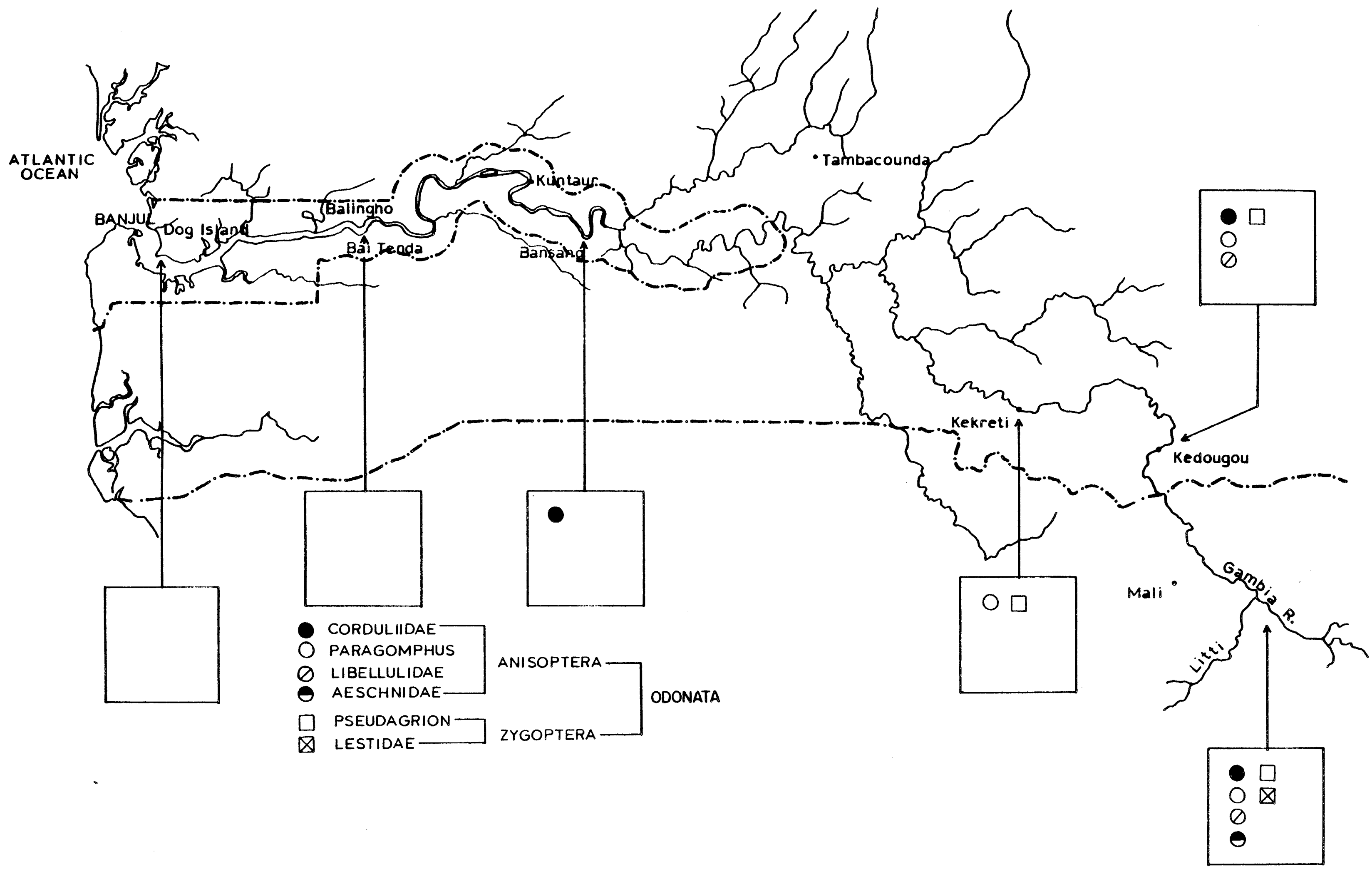


FIG. 19. The occurrence of Odonata (dragonflies) in the Gambia River.

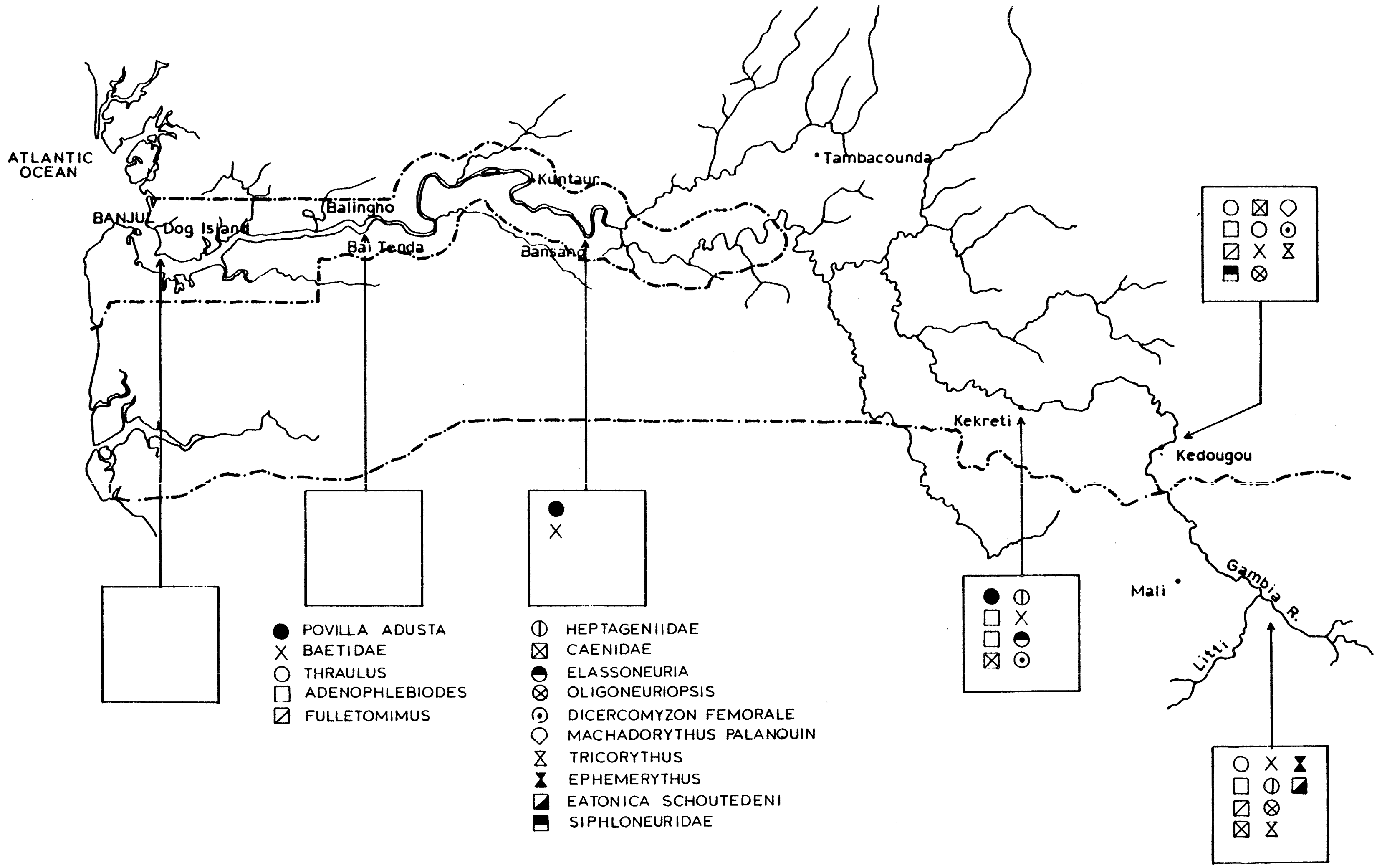


FIG. 20. The occurrence of Ephemeroptera (mayflies) in the Gambia River.

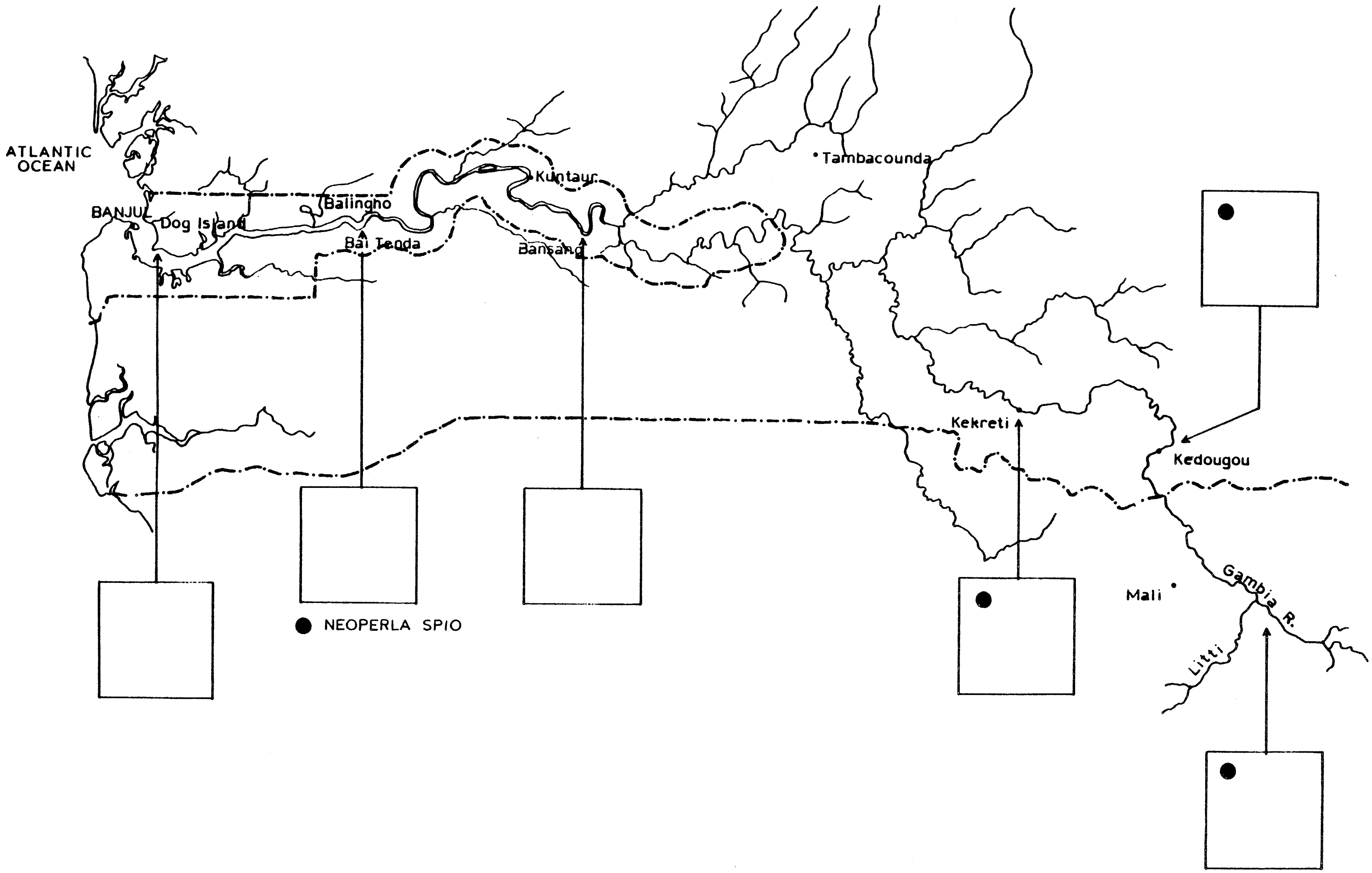


FIG. 21. The occurrence of the stonefly Neoperla spio in the Gambia River.

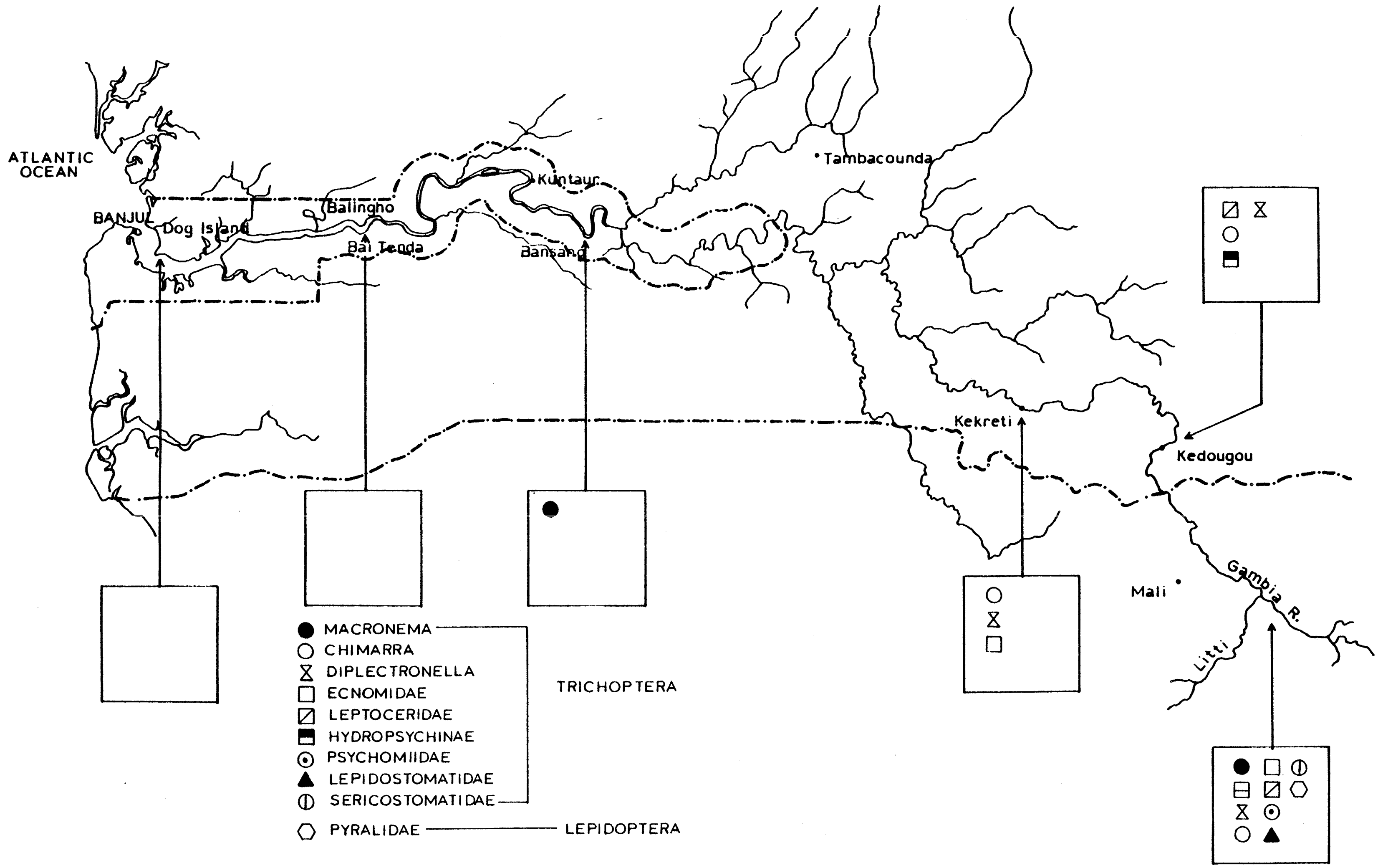


FIG. 22. The occurrence of Trichoptera (caddisflies) and Lepidoptera (aquatic moths) in the Gambia River.

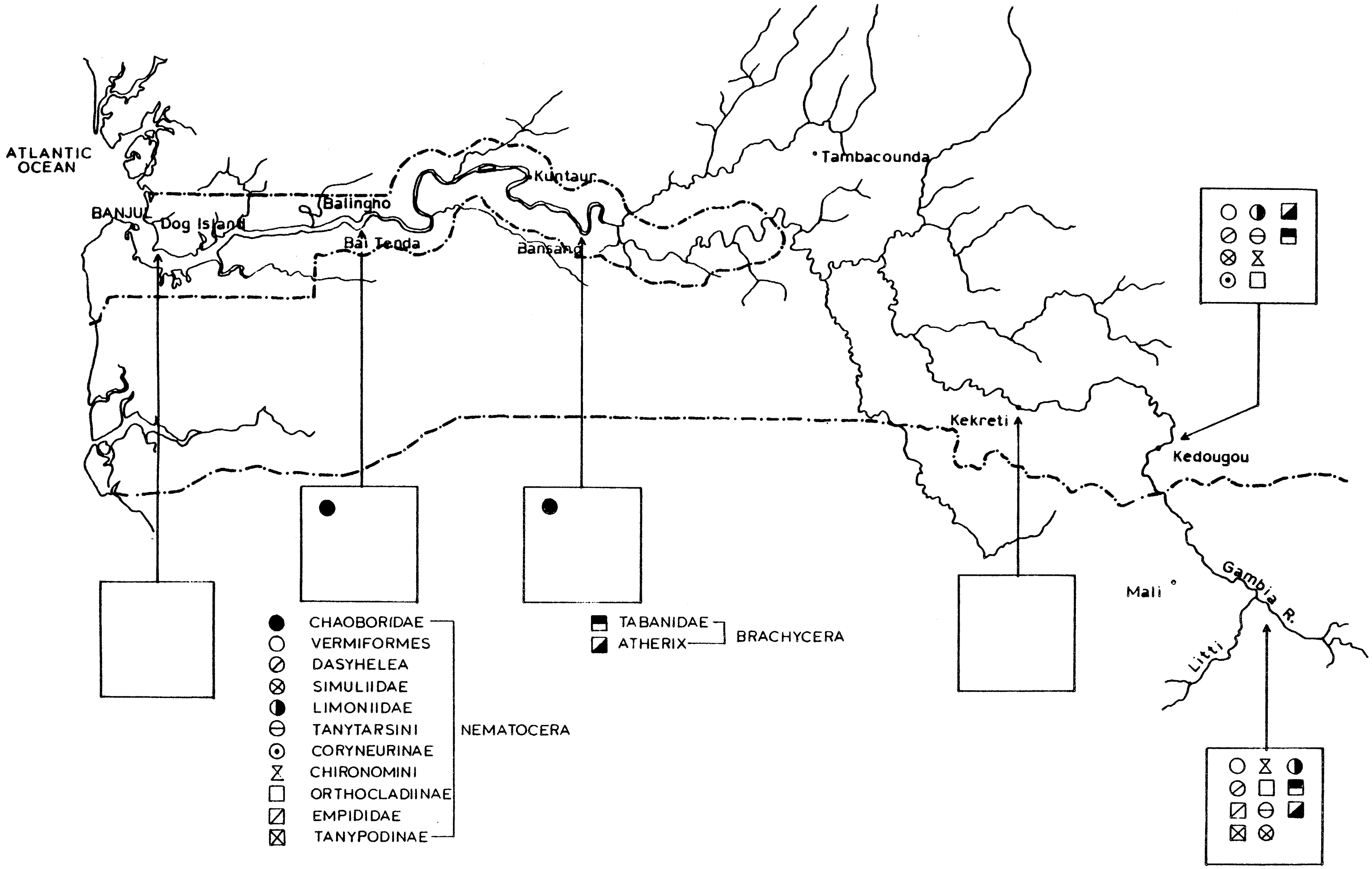


FIG. 23. The occurrence of Diptera (flies, midges, and mosquitoes) in the Gambia River.

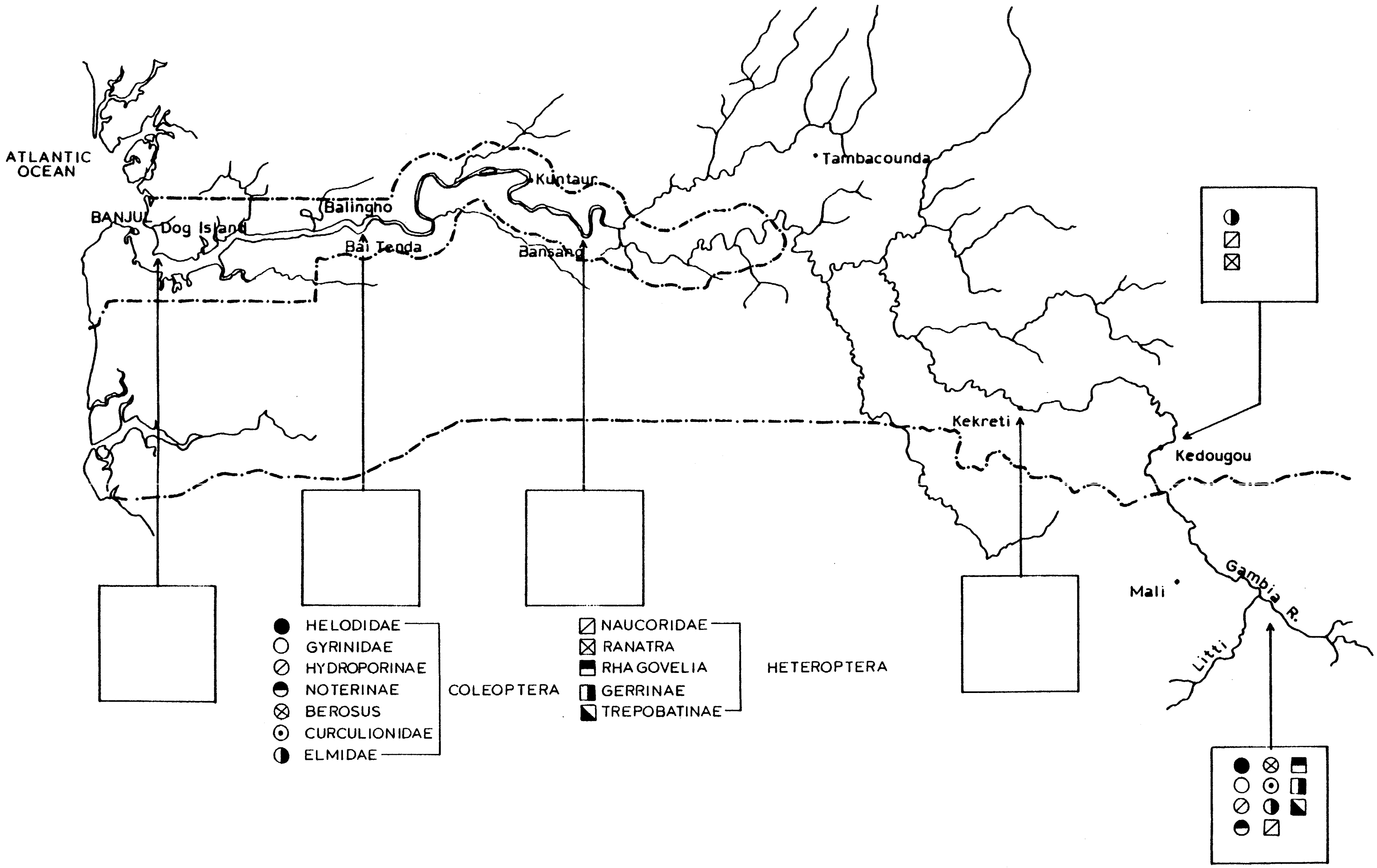


FIG. 24. The occurrence of Coleoptera (beetles) and Heteroptera (waterbugs) in the Gambia River.

salinities below 25 ppt. The most important marine invertebrates still found as far upstream as Bai Tenda in the upper estuary crabs were the _Callinectes_ spp. and the penaeid shrimp. These animals need the estuarine environment to complete their life cycle, although reproduction takes place at sea. Juvenile pink shrimp, _Penaeus duorarum_, can survive and grow over a wide range of salinities (Hoestlandt 1969, Zein-Eldin 1963), but they find food and protection from predators at the low salinities among the mangrove vegetation. The oyster _Crassostrea gasar_ colonizes large stretches of mangrove during the dry season, but dies off during the rainy season in those parts of the river with a large salinity reduction. This invertebrate was considered a temporary inhabitant of the upper estuary. The few oysters that survive at the more favorable sites will provide the pelagic larvae needed to recolonize the rest of the mangrove during the next dry season (Plaziat 1982).

Permanent inhabitants of the upper estuary are the genuine brackish water species, all descending from marine ancestors, which find their physiological optimum somewhere in the range between fresh water and euhaline salinities. In general, they are represented by low species diversity, but high abundances. A good example is the gastropod _Tympanotonus fuscatus_. Distinct from the marine members of the Cerithidae, _T. fuscatus_ is viviparous, thus protecting the young stages from salinity fluctuations in the estuarine environment. The high degree of polymorphism in _T. fuscatus_, as well as in _Neritina_, the other snail very abundant in the mangroves, is considered by Muus (1979) as a general feature of euryhaline animals. The polymorphism is a result of high genetic diversity within the populations, another strategy of adaptation to the unstable estuarine environment (Plaziat 1982).

Among the Crustacea, the shrimp *Nematopalaemon hastatus* was considered an estuarine species, because gravid females occurred in the upper estuary at a mean salinity of about 11 ppt. Several euryhaline species reach maturity in brackish water at a smaller size and younger age than at sea. The size of the ovigerous females of *Crangon* found in the upper estuary of the Gambia River was even smaller than that mentioned by Muus (1967) for gravid females of this shrimp observed in the Baltic. The higher temperatures in the tropical estuary which increase metabolic rates, may be responsible for maturity at this very small size (15 mm). The occurrence of high numbers of ovigerous females of *Palaemonetes* at salinities from 5 to 11 ppt indicates it to be a true brackish water species.

With increasing distance from the river mouth, salinity decreases faster and fluctuates more intensively in the water column than in the bottom substrate (Kinne 1966). This might explain why, in the lower river near Bansang where the water was fresh throughout the year (Fig. 25), nereid Polychaeta were found in the bottom mud. The composition of benthic fauna living on the muddy substrate of the rather deep and turbid waters of the lower river resembles to some extent that of lake bottom communities. The burrowing mayfly nymphs, odonate nymphs, and Chaoboridae found in the lower river are characteristic of a lake environment. Also, the clam *Corbicula africana* is very common in African lakes.

Compared with the lower course of the Gambia River, the upper river zone shows an increase in taxonomic diversity of benthic fauna, directly related to the number of ecological niches available. The variety in river habitats is much higher in the upper river and headwaters than downstream in the Gambia River.

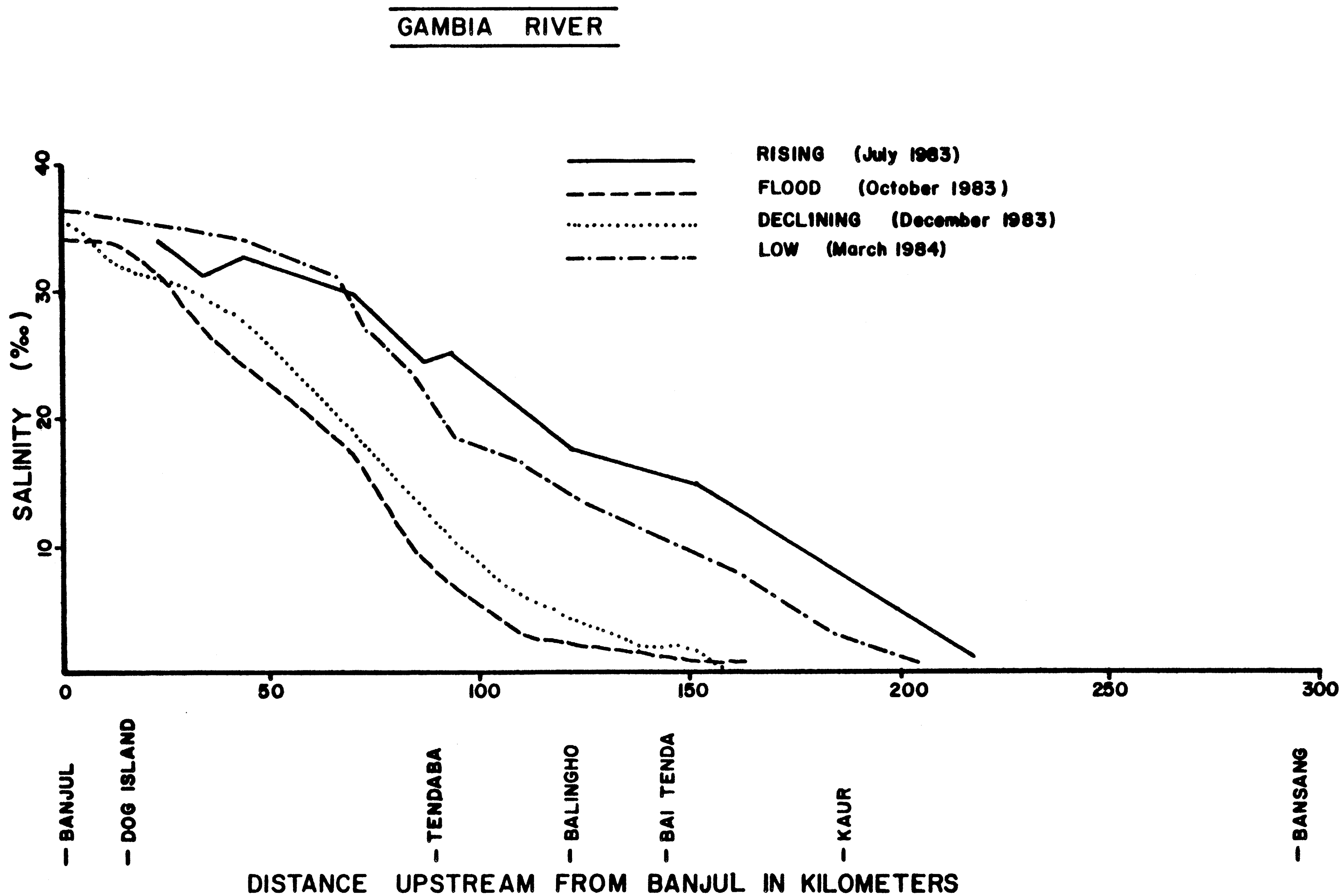


FIG. 25. Salinities in the Gambia River during different hydrological periods (rising water, floods, declining floods, and low water).

Cummins (1980) has classified the benthic invertebrates of streams into functional feeding groups. He found a shift in the ratios of the different groups, particularly the insects, occurs along the river or stream. A similar trend was observed in the Gambia River. The upper course of the Gambia River harbored a high proportion of shredders: larvae of Plecoptera, case-dwelling Trichoptera, and Tipulidae (Limoniidae). In the middle course of the river, grazing invertebrates, scraping periphyton off the bottom substrate, were well represented by the different mayfly groups and by the snail Bellamya unicolor. Predators, such as the nymphs of Odonata, formed a rather constant proportion of the freshwater benthos, both upstream and downstream. Blackfly larvae, which are filtering food collectors, dominate in the headwaters of the Gambia River. In general, the importance of terrestrial input of coarse particulate organic matter (dead leaves, branches, etc.) is highest in the headwaters and decreases downstream, explaining the high proportion of shredders in the upper course of the river and their disappearance in the lower river zone. Development of the Gambia River Basin will result in changes of stream flow, light penetration, and thermal regime of the river and modify the quantity and quality of detritus input (particulate organic matter and dissolved organic matter). These alterations will provoke a major restructuring of the river benthos communities resulting in important shifts in the faunal composition.

COMMERCIALLY IMPORTANT INVERTEBRATES

Shrimp

Shrimp fishing in The Gambia takes place mainly in the estuary, where the shrimp are caught by means of stake nets, a gear commonly used in West Africa. The catches in the estuary consist almost exclusively of the pink shrimp,

Penaeus duorarum. Some Guinea shrimp, Parapenaeopsis atlantica, are captured near the river mouth. The pink shrimp fishing area extends up the Gambia River as far as Jappeni, about 150 km from the river mouth of Banjul. Estuarine shrimp fishing on a large scale is carried out by the National Partnership Enterprise, Ltd. (NPE) in Banjul. Its organization and the economic importance of the shrimp fishery in The Gambia are discussed by Josserand (1984).

The pelagic stake nets used on the Gambia River for shrimp fishing have a mesh width of 14 mm. Two nets are attached to either side of an anchored canoe by means of cross-beams, each 2 m long, supported by floats; the cross-beam, together with two vertical stakes, keeps the pouch-shaped net in an open position. Fishing takes place mainly at night, during ebbtide. The nets are lifted before the current reverses. The size of the pink shrimp, sold by the N.P.E. in Banjul, varies from about 10 cm ("grade 7") to about 20 cm ("grade 1"), measured from the tip of the rostrum to the tip of the tail fan.

Penaeus duorarum --

Data concerning the life cycle and biology of Penaeus duorarum in its African distribution area are provided by Hoest-Landt (1969), who studied the pink shrimp in Dahomey, by Garcia (1978) reviewing research from the Ivory Coast and in a series of scientific documents by Lhomme (1978a, 1978b, 1979a, 1979b) from Senegal. The biology of P. duorarum can be summarized as follows: Adult pink shrimp are found offshore in waters with a temperature range of 18° - 24°C near the surface and a minimum temperature of 15° - 16°C near the bottom. Salinities have to be over 35 ppt for the reproducing populations of P. duorarum. Moreover, their distribution depends on the presence of estuaries and lagoons along the coast, as well as on sediments rich in organic matter.

The highest concentrations of adult pink shrimp are found on substrates containing over 50% of fine organic particles. Mating and spawning of the shrimp take place at sea. The larval stages, protozoe and mysis, are marine. The postlarvae migrate into estuaries and lagoons through passive displacement by the incoming tidal current. The shallow waters of the estuarine nursery grounds provide food and protection to the young shrimp as they grow for about 2.5-3 months. When the shrimp have attained a carapace length of 16-17 mm, corresponding with a total body length of about 70 mm, they start to migrate toward the sea. Migration takes place at night, during ebbtide. A maximum migration of preadult shrimp occurs during the annual floods, when salinity is reduced and the currents are fast. *Penaeus duorarum* reproduces for the first time at the age of 6-7 months (carapace length 27-30 mm). The longevity of the pink shrimp is at least 23 months.

Penaeus duorarum was collected in the Gambia River in substantial numbers, both in the trawl and gill nets, in October (peak of the annual flood). Figure 26 shows the composition of the trawl samples from the lower estuary in different hydrological periods. It can be seen that when the floods declined pink shrimp formed only a small portion of the samples. It was virtually absent during the dry season in the trawl samples (mid-channel of the river). The high abundance of pink shrimp in October was probably the result of maximum migration of preadults, occurring when salinities are reduced and currents are fastest (Garcia 1978, Crosnier and Debondy 1967).

Figure 27 shows the relationship between cephalothorax (= carapace) length and body length for *P. duorarum*. Because part of the rostrum was often lacking in the shrimp from the trawl samples, body length was measured from the orbital notch to the tip of the tail fan (telson), instead of the normal measurements

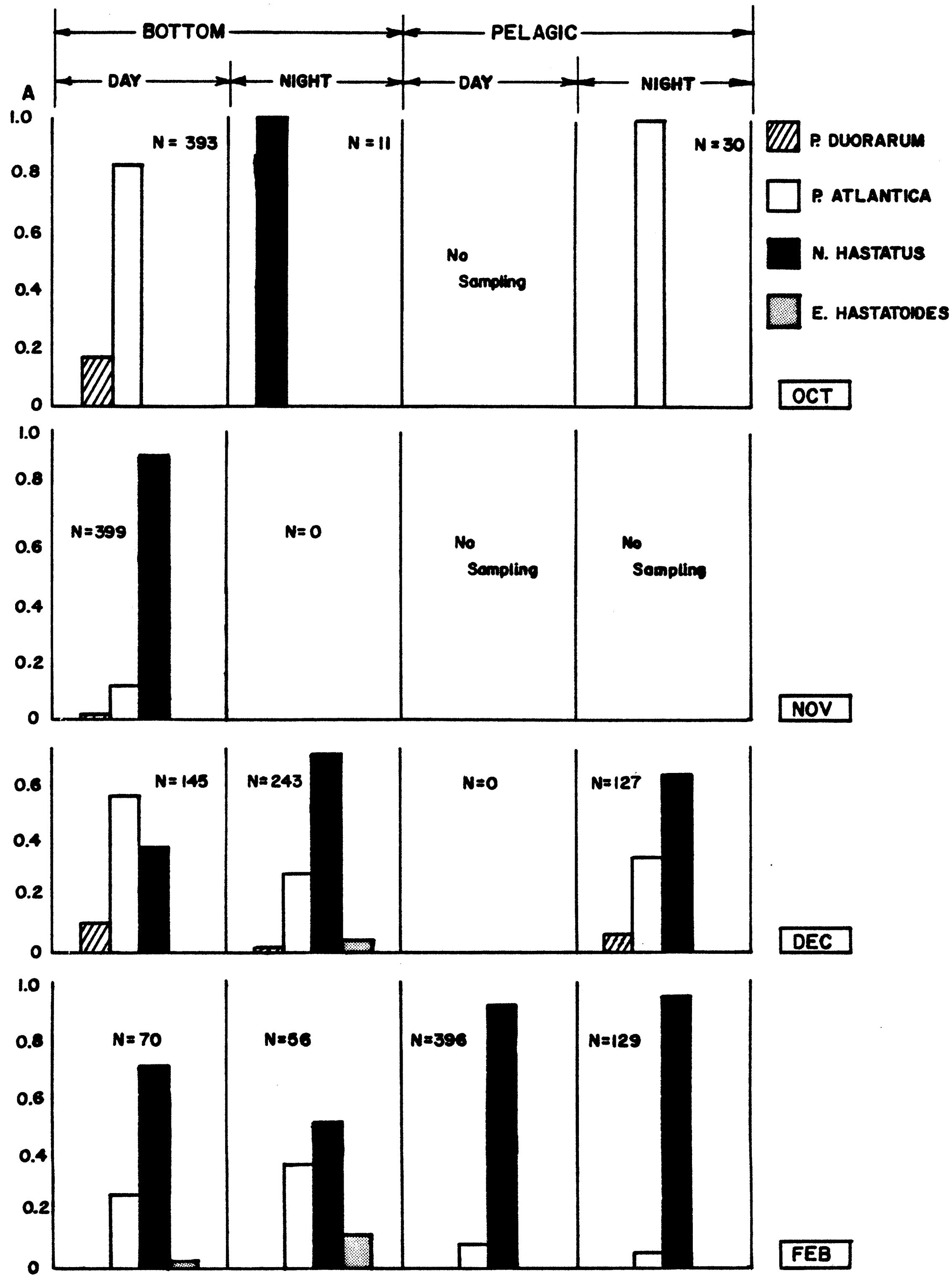


FIG. 26. Composition of the shrimp trawl samples from the lower estuary of the Gambia River in October, December, January, and February.

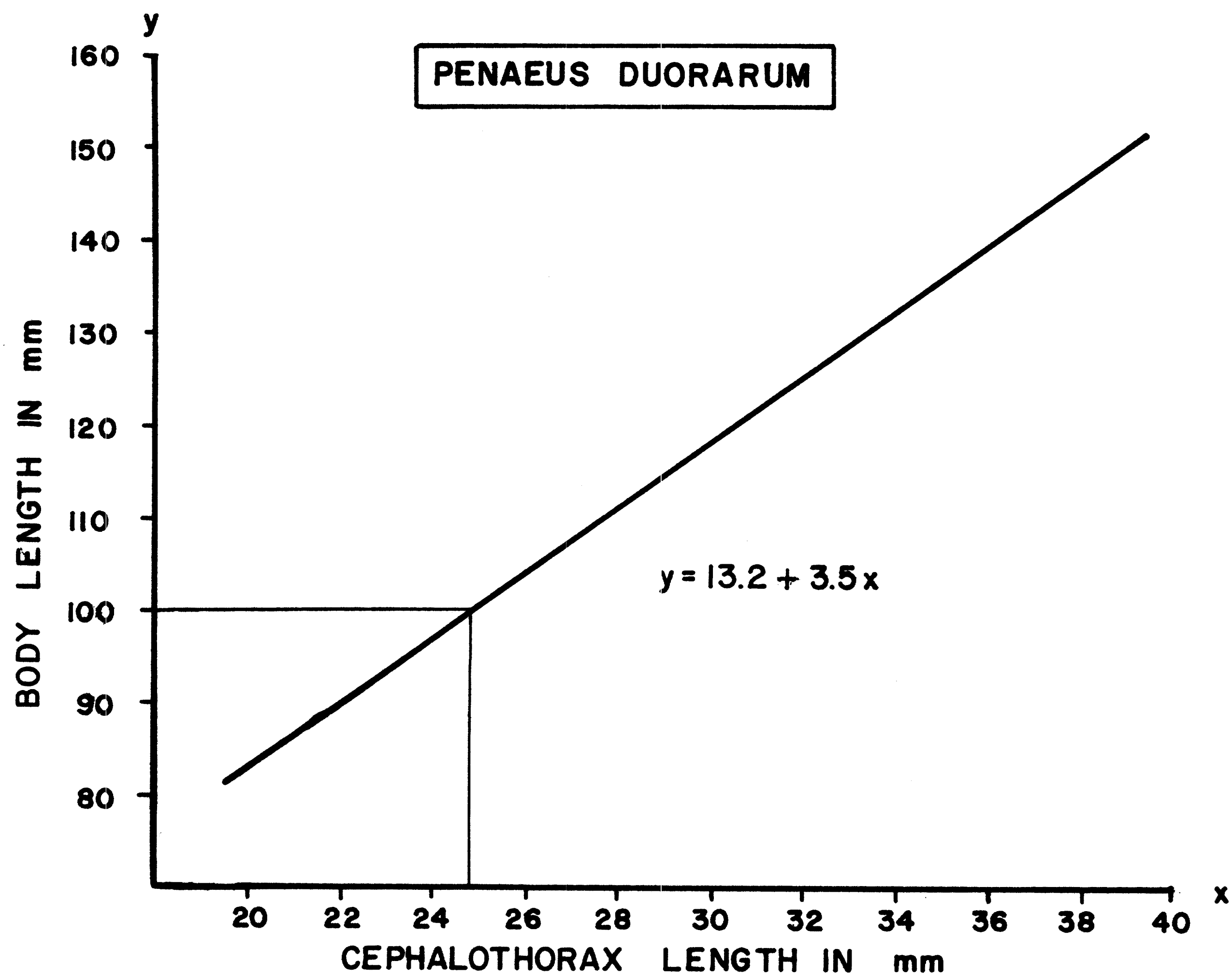


FIG. 27. Relationship between cephalothorax length and body length of the pink shrimp Penaeus duorarum.

from the tip of the rostrum. A maximum cephalic length of 42 mm and a body length of 161 mm was measured for pink shrimp from the Gambia River. Figure 28a shows the size distribution of pink shrimp in a sample from the mid-channel of the river and in a sample from the shallow waters near the river bank. The animals caught in the middle of the river were, on the average, larger than those near the shore (mean cephalic lengths 22 mm and 13 mm, respectively). This can be explained, in part, by a preference of the preadult shrimp to migrate in the center of the river. The smaller juvenile shrimp, not yet ready to migrate toward the sea, dominate along the river banks. Comparison of the size composition of the samples from the flooding and low water periods shows a similar distribution (Fig. 28b). The shrimp were generally larger during the dry season, when the strong stimulus of fresh water was lacking and seaward migration delayed. Low salinities in the estuary during the wet season prompt the shrimp to migrate at a younger age (Lereste 1983).

Figure 29 presents the monthly shrimp catches of NPE from the Gambia River from July 1982 to July 1984. Shrimp yield was maximal during the wet season and a second, but lower, peak occurred at the end of the dry season (April-June). This pattern is in agreement with the observations by Lereste (1983) concerning *Penaeus duorarum* in the Casamance estuary. A maximum in rainfall was followed by a peak in shrimp catch (Fig. 29). A high correlation exists between estuarine shrimp catches and migration of the preadult *P. duorarum*. Variations in the catches reflect variations in the amount of migrating shrimp (Garcia 1977, 1978). The periods of highest shrimp yield from the river are those in which migration toward the sea is most intense. Lhomme (1979b) observed that a maximum in the estuarine shrimp catches is followed by a maximum shrimp yield at

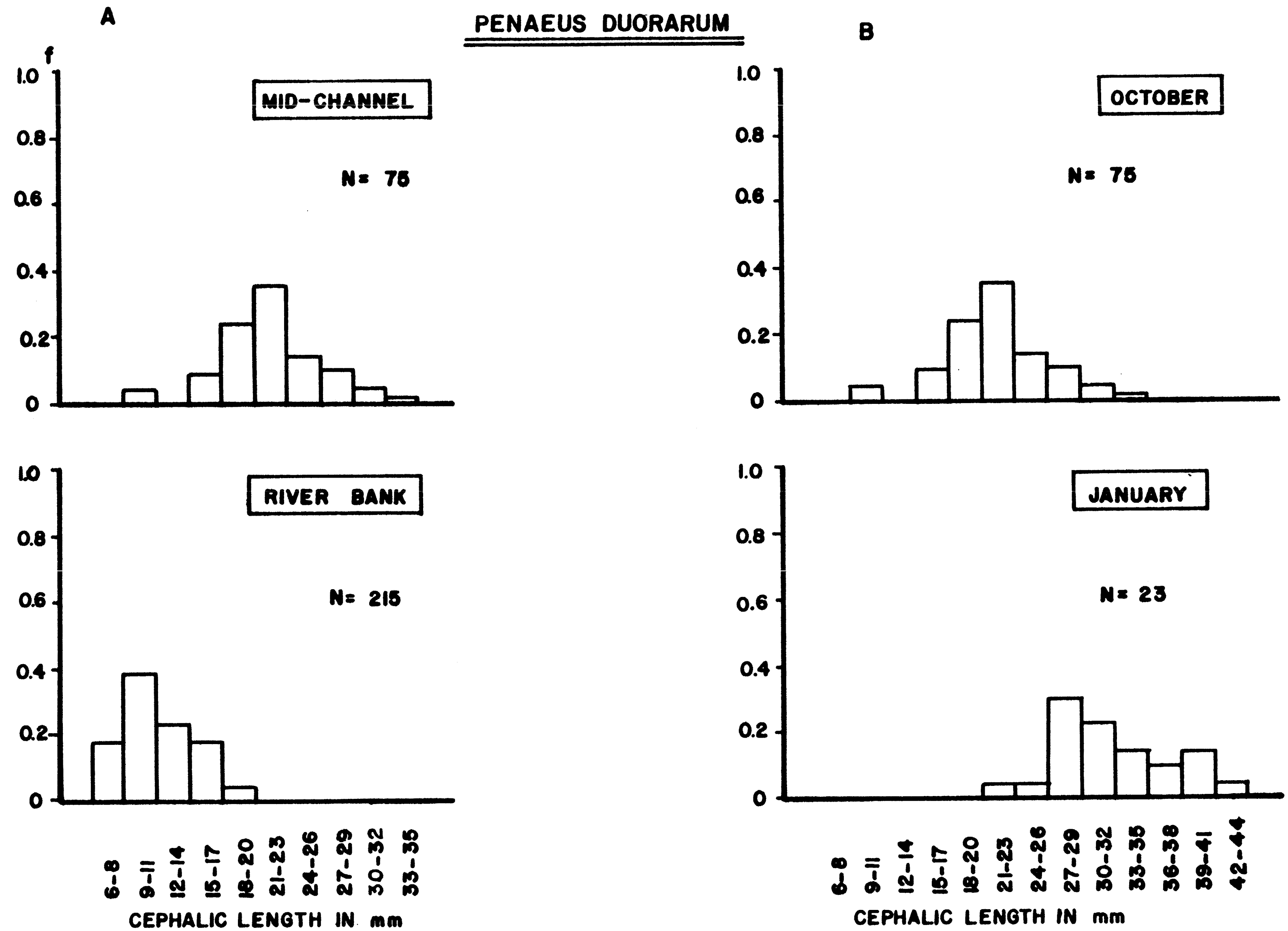


FIG. 28. a/ Size distribution of pink shrimp in samples from the mid-channel and from near the banks of the lower estuary. b/ Size distribution of pink shrimp in samples from the lower estuary collected during the annual floods and during the dry season.

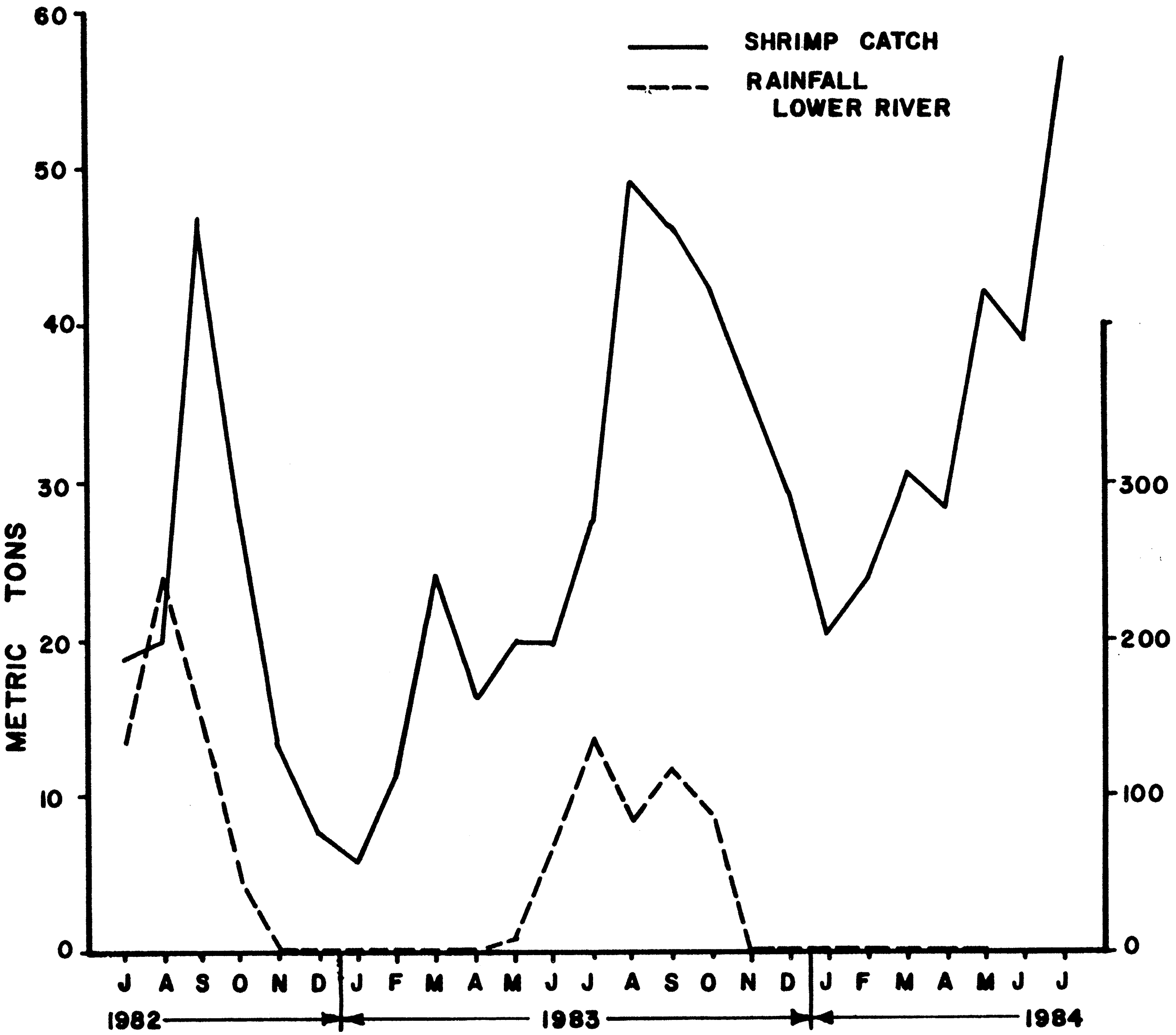


FIG. 29. Monthly catches of shrimp in the Gambia River, recorded by the N.P.E. Ltd. in Banjul over the period July 1982–July 1984, and mean rainfall on the lower river.

sea, confirming the positive relationship between estuarine shrimp catch and the migration down the river of the preadult shrimp.

Because the shrimp catches are expressed in weight, the second peak occurring at the end of the dry season (Fig. 29) may represent fewer animals, but of larger size and weight than during the wet season maximum. When estuarine salinities are high, as in the dry season, the juvenile shrimp spend a longer period in the river and thus start to migrate at a larger size than during the rainy season. Lereste (1980, 1983) established a correlation between pink shrimp yield in the Casamance estuary and rainfall. The higher the salinities during the wet and dry seasons, the longer the shrimp stay in the estuary and the higher the shrimp catches will be. The amount of rainfall of the previous year determines to what extent salinities will be reduced in the course of the next dry season, thus affecting the amount of shrimp yield at the end of the dry season. The maximum yield occurring at the end of the wet season is determined by the amount of rainfall of the same year and to a lesser extent by that of the previous year(s).

An increase in shrimp catches was observed in the Casamance with the overall decrease in rainfall during the past fifteen years. Also in The Gambia, shrimp catches were better after a year of low rainfall. The year 1983, for example, was a year of drought (Harza 1985), which was reflected by a higher shrimp yield in 1984 compared to that in 1983 (Fig. 29). The total shrimp catch for July 1984 amounted to almost 57 metric tons, while during the first half of August 1984 51.2 metric tons of shrimp were recorded by the NPE. Near Balingho and farther upstream, near Jappeni, the amount of shrimp harvested in July 1983 was 10.8 metric tons, whereas in July 1984, 19 metric tons of shrimp were caught. Moreover, in July 1984 the NPE shrimp factory could extend their

fishery area even farther upstream to Bambali, about 10 km past Jappeni. Saltwater intrusion in the Gambia River reached as far as Bambali in December 1983. During the low water period, in March, the boundary of the estuary had proceeded even farther upstream, near Carrol's Warf, 207 km from Banjul (Fig. 25) (Berry et al. 1985).

Shrimp fishing in The Gambia is entirely based on the biology and behavior of the pink shrimp and concentrates of the migrating preadult shrimp, which are the largest in size among the estuarine shrimp populations. The nets are set near the river banks or in the bolons, in places where some channeling exists (usually channeling of the river bottom is an indicator of fast currents). Fishing takes place at night, during ebbtide, when the shrimp are active and migrate seaward using the tidal current. The best catches were recorded during new moon. During other lunar phases good catches were also obtained, but only if there were strong currents resulting from the tide or wind. A correlation of shrimp migration and catches with current velocities is mentioned by Garcia (1977), who studied *P. duorarum* in a lagoon in the Ivory Coast. In the upper estuarine reaches of the Gambia River near Bai Tenda, velocities of 2.75 km per hour for the flood current and of 3.50 km per hour for the ebb current were measured during the annual floods of the river (Berry et al. 1985).

The portion of the Gambia River over which shrimp fishing extends varies according to the seasons (Table 7). Toward the end of the dry season pink shrimp were caught as far upstream as Jappeni, at about 150 km from the river mouth (Fig. 30). During the wet season, when low salinities prevail in the upper estuary, the upstream fishing grounds were abandoned and shrimp were caught only in the lower estuary: Banjul, Mandinari, Tubacolon, Pirang, and Albreda (Fig. 30). Figure 31 shows the monthly shrimp catches over the period

TABLE 7. Fishery stations of the National Partnership Enterprise, Ltd. in Banjul and months of the year, from which shrimp catches were recorded for the different stations (see Figure 30).

	1983												1984						
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Banjul	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Essau	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	-	-
Mandinari	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Tubacolon	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pirang	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Faraba	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Albreda	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sami	x	x	x	x	x	x	-	-	-	-	-	-	-	x	x	x	x	x	-
Jurunku	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-
Bintang	-	-	-	-	-	-	-	-	x	-	-	-	-	x	x	-	-	-	-
Tankular	-	-	-	-	x	x	-	-	-	-	-	-	-	-	-	x	-	-	-
Tendaba	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	x	x	x	x
Jiroff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x
Jasobo	-	-	-	-	-	x	x	x	x	-	-	-	-	-	-	x	x	x	x
Balingho	-	-	-	-	-	x	x	x	x	-	-	-	-	-	-	x	x	x	x
Yelitenda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-
Jappeni	-	-	-	-	-	x	x	x	x	-	-	-	-	-	-	-	x	x	x
Bambali	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x

x = shrimp catch recorded
- = no shrimp catch

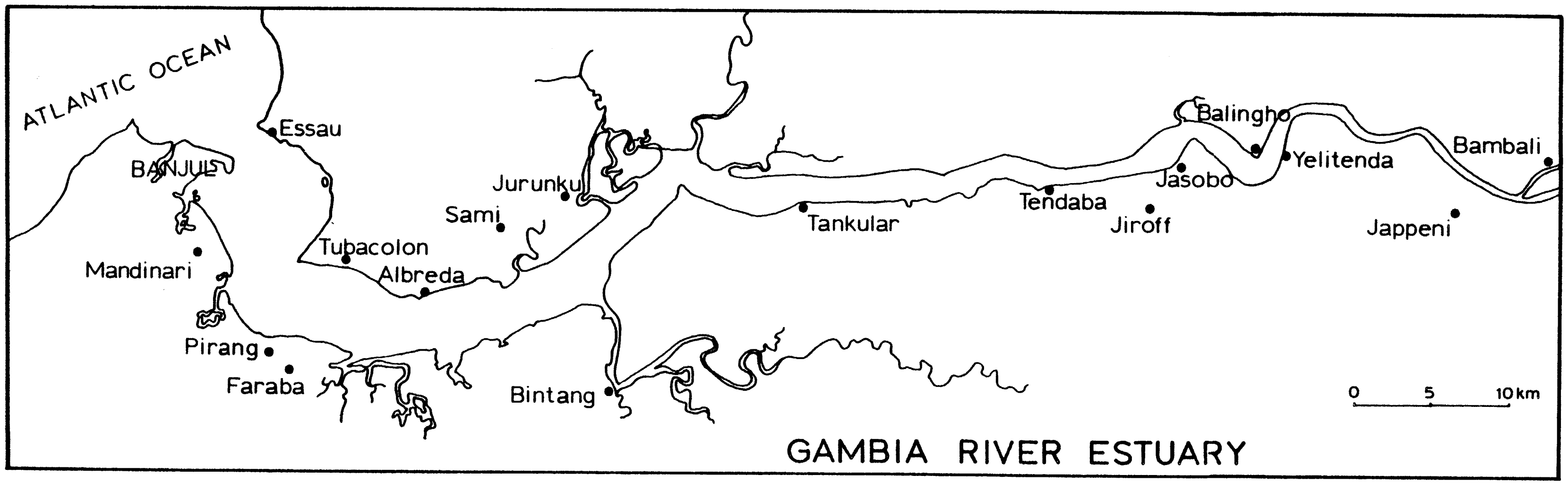


FIG. 30. Shrimp fishing stations of the N.P.E. shrimp factory in Banjul along the Gambia River.

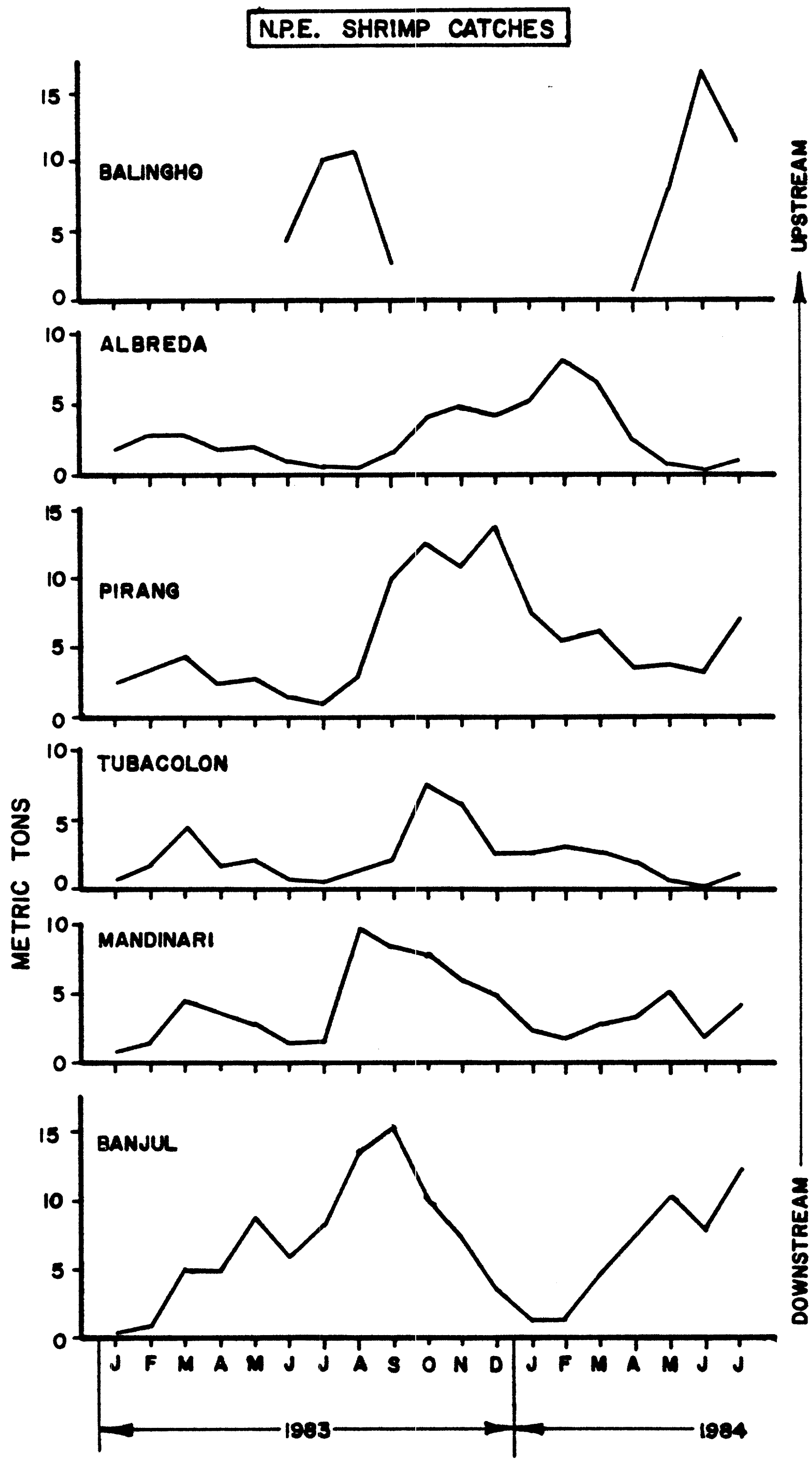


FIG. 31. Monthly shrimp catches, over the period January 1983-July 1984, at different stations along the Gambia River.

January 1983-July 1984, at different localities in the Gambia River. Near Balingho and Jappeni, shrimp fishing takes place only during part of the year. Fishing started toward the end of the dry season (March or April) and ended before the flooding of the river was maximal (October), when salinities in the upper estuary were so reduced that preadult shrimp could not remain in this part of the river. In the lower estuary shrimp fishing is possible throughout the year, although seasonal fluctuations occur in the shrimp catch. Table 8 shows the percentages of total shrimp catch in 1983, represented by the different shrimp fishing stations in the Gambia River. The fishing grounds near Banjul yielded more than 25% of the total catch. The amount of shrimp caught near Balingho, the possible site of the salinity barrage, and upstream from Balingho was almost 10% of the total catch, although the stocks were exploited only during a short period of the year in that part of the river. The lower estuary provided as much as 82.8% of the total shrimp catch in 1983.

Because pink shrimp, *Penaeus duorarum*, is a highly valuable export for The Gambia, any change in the shrimp production that might occur will affect the local economy. For this reason, an attempt has been made to assess the impacts on the shrimp stocks from environmental modifications resulting from the construction of a salinity barrage near Balingho. The ecological requirements of each important stage in the life cycle of *P. duorarum* is reviewed in relation to those changes in the natural environment that may occur following river impoundment. Only changes that will directly affect a particular shrimp stage are considered below.

Adult off-shore shrimp stock -- Adult *Penaeus duorarum* are found offshore on muddy substrates with a high organic matter content. The highest concentra-

TABLE 8. Shrimp catches of the N.P.E. for each station along the Gambia River in 1983 (total shrimp catch 326.6 metric tons) and percentages of the total catch represented by the different stations.

	catch in metric tons	% of the total catch
Banjul	83.5	25.6
Essau	4.4	1.3
Mandinari	52.5	16.1
Tubacolon	31.8	9.7
Pirang	66.3	20.3
Albreda	26.5	8.1
Sami	5.5	1.7
Bintang	0.08	0.02
Tankular	0.5	0.2
Tendaba	11.8	3.6
Jasobo	12.0	3.7
Balingho	27.2	8.3
Jappeni	4.6	1.4

tions of pink shrimp occur on sediments with a content of more than 50% fine organic particles (Garcia 1974). Such spawning grounds are found along the West African coast in places with a strong influence of continental water discharge. Crosnier and Debondy (1967) mentioned with respect to *P. duorarum* that, although this shrimp is generally found at depths of 30 to 75 m, its depth distribution is different near estuaries, where adult pink shrimp may occur in coastal waters only 10 to 15 m deep.

The amount of organic matter deposited offshore by the Gambia River, particularly during the wet season, will decrease to a large extent as a result of the projected streamflow regulation. As a consequence, the size of the adult offshore shrimp stocks may be affected. Moreover, the reproduction rate of *P. duorarum* could be impaired, because it appears governed not only by temperature, but also by continental discharge and primary productivity (Lhomme 1979a).

Postlarvae -- The postlarvae of *Penaeus duorarum* require the shallow, estuarine environment to grow and attain the preadult stage. The postlarvae depend upon the tidal currents and salinity gradients for their migrations toward estuaries and lagoons. Hughes (1969) demonstrated experimentally that pink shrimp larvae respond to current direction and salinity gradients in such a way as to facilitate their entry into estuarine waters. The opportunity to penetrate an estuary is closely linked to hydrological conditions (coastal and tidal currents, water balance of the river, etc.).

A maximum abundance of postlarvae in the water column occurs at night, during the incoming tide, particularly at new moon. During the day the postlarvae remain buried in the substrate. Figure 32 shows the abundance of postlarvae near Banjul at different times of the night and of the tidal cycle.

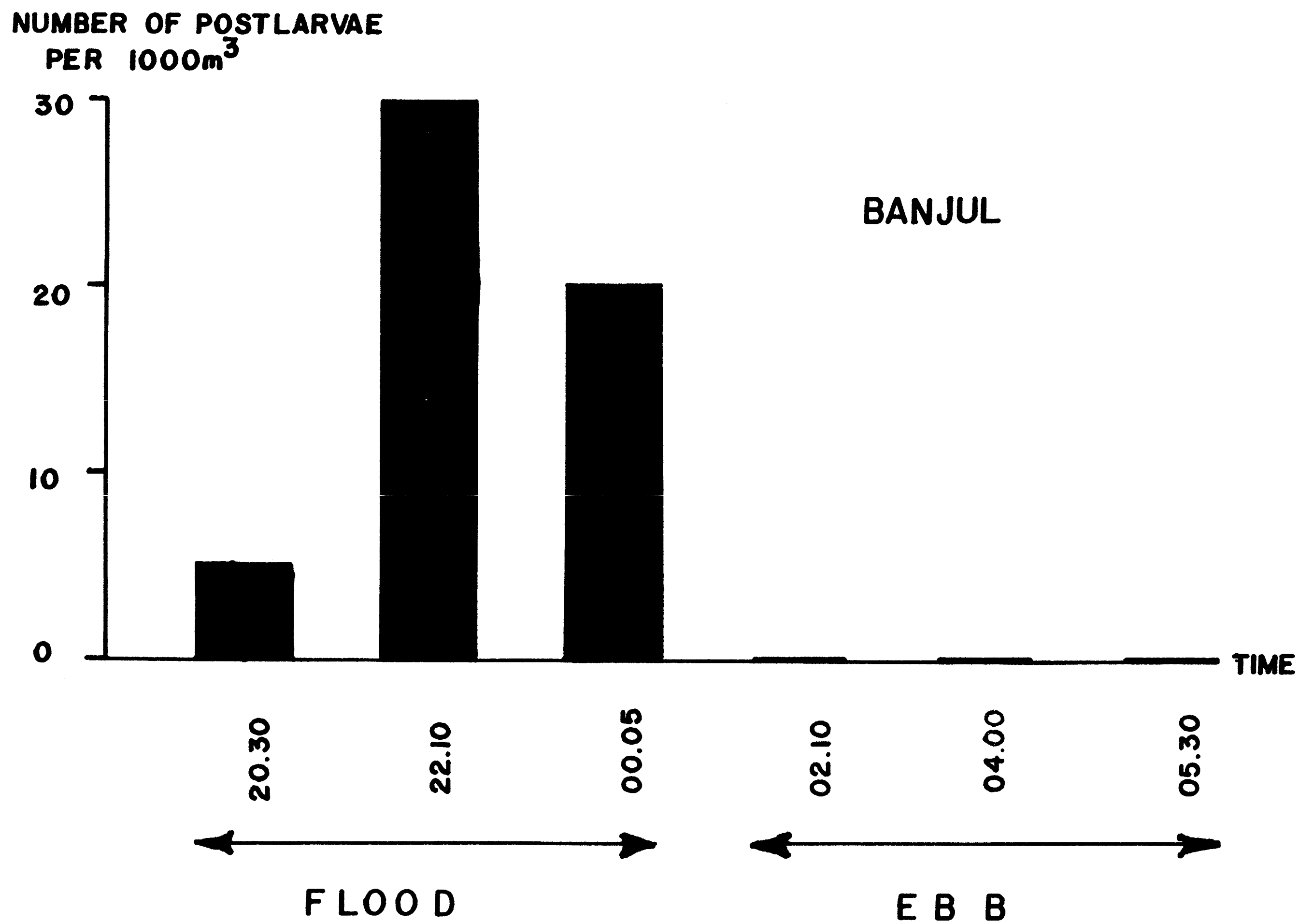


FIG. 32. Number of postlarvae of Penaeus duorarum per 1,000 m^3 in the Gambia River near Banjul and different times of the night and tidal cycle during new moon (after data by Lhomme 1976).

Lhomme (1976) collected postlarvae by plankton tows in the Gambia River near Banjul. He established that the abundance of pink shrimp postlarvae in the Gambia River estuary was very low compared to that of the Sine Saloum (Senegal) during the same period of the year. Although little is known about the origin of the postlarvae found in the Gambia River, it is assumed that they are supplied by the adult shrimp populations occurring near Cape Roxo and the Bissagos Islands (Fig. 33) (Lhomme 1979b). The prevailing surface currents off the coast of West Africa are orientated South-East, but the coastal waters of the continental shelf undergo a counter-current in a northwestern direction, which might transport the postlarvae from the Roxo-Bissagos spawning grounds toward the mouth of the Gambia River.

According to Garcia and Lereste (1981), flooding of the river during the rainy season appears to favor the penetration of postlarvae into the estuary, because it may increase the extent of the coastal zone with a strong salinity gradient to which the postlarvae orient themselves. Therefore, a very strong decrease in freshwater flow as a result of the Balingho Salinity Barrage can be expected to have a major impact on the recruitment of pink shrimp postlarvae in the Gambia River, thus in turn affecting the size of the estuarine juvenile shrimp stock.

Juvenile shrimp -- After the postlarvae have entered the river, they quickly transform into juvenile shrimp. Young *Penaeus duorarum*, although usually found at low salinities, can both survive and grow over a wide range of salinities (Zein-Eldin 1963, Hoestlandt 1969). Therefore, it is assumed that low salinity is not a requirement for the young shrimp, but that the food and protection from predators offered by the estuarine habitats are the key factors

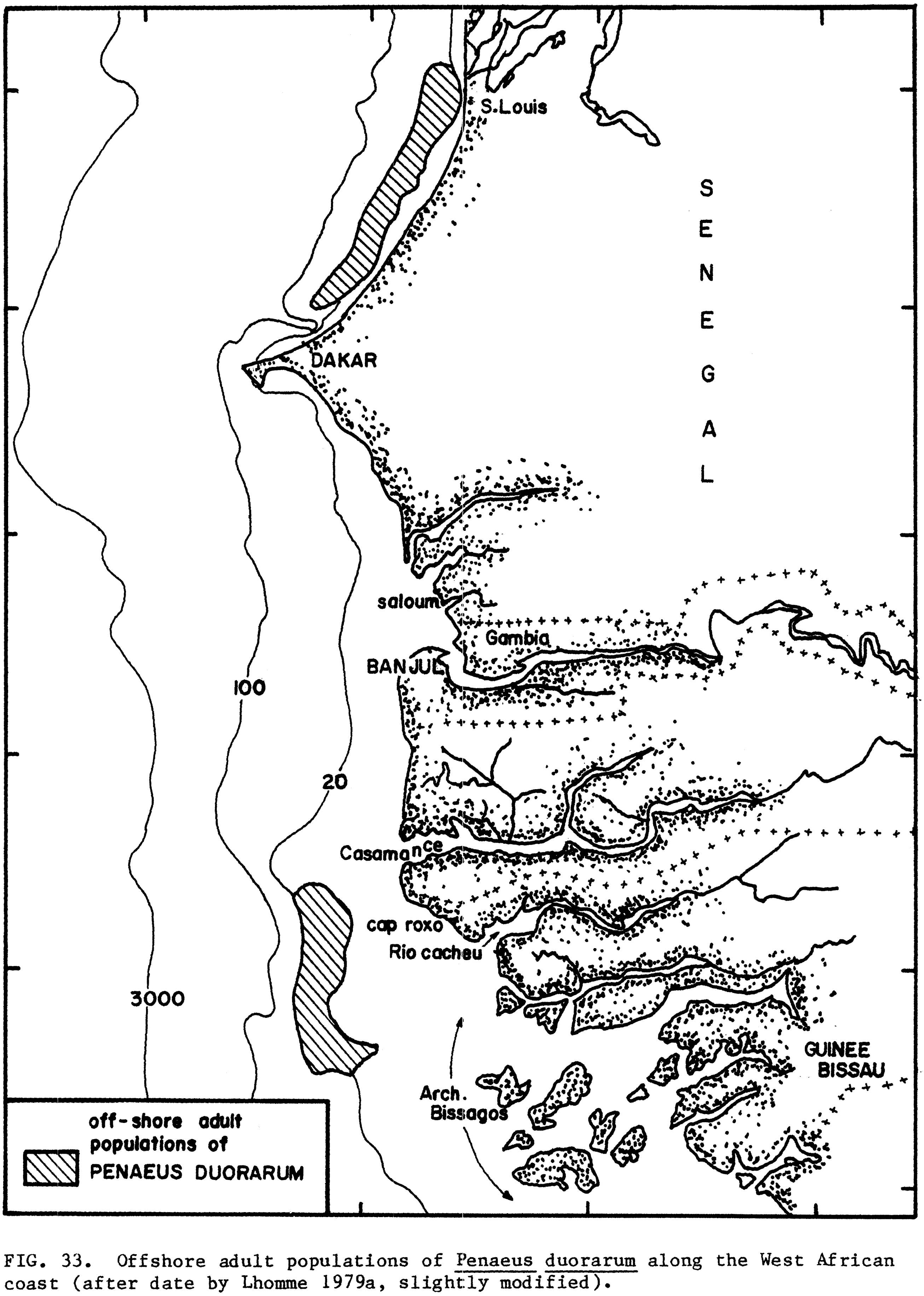


FIG. 33. Offshore adult populations of Penaeus duorarum along the West African coast (after date by Lhomme 1979a, slightly modified).

for their growth and survival. Lereste (1982), in his study on the distribution of young _P. duorarum_ in the Casamance estuary, reported that the upstream distribution limit of the juvenile shrimp coincides with the upstream boundary of the mangrove vegetation. According to Pedini (1982), mangroves play a very important role in the life history of many economically important penaeid shrimp; young shrimp feed on the mangrove detritus (leaves) which is greatly enriched by an extensive growth of bacteria and fungi. Shelter against predation is provided by the intricate roots of the mangrove trees.

While the salinity changes are not expected to affect the young pink shrimp directly, because of their tolerance toward different salinities, changes in the mangrove vegetation due to permanently high salinities downstream from the barrage will have an impact on the overall productivity of the pink shrimp. Also, after the construction of the Balingho Salinity Barrage, shrimp fishing will not be possible upstream from Balingho, which means an estimated yearly loss of about 10% of the present-day shrimp catch.

Preadult shrimp -- Migration of preadult _Penaeus duorarum_ takes place at night, during ebbtide. Downstream migration of the shrimp is correlated with reductions in salinity and increased current velocity. Maximum migration occurs when the river is flooding. Preadult pink shrimp, less tolerant of reduced salinities than the younger stages, are orientated in a seaward direction by the positive salinity gradient of the estuary.

The construction of the salinity barrage will result in drastic changes in salinity, particularly in the upper estuary. Delayed downstream migration of _P. duorarum_, due to permanently high salinities, may produce an increase in shrimp yield downstream from Balingho, because the migrating shrimp will be of larger

size and weight than at present. On the other hand, if virtually no fresh water reaches the estuary, as may be the case if all the water of the Balingho Reservoir is utilized for irrigation, tidal mixing will cease completely downstream from the barrage. Consequently, the positive salinity gradient of the Gambia River estuary will disappear or even be converted into a reverse salinity gradient, similar to that presently existing in the Casamance estuary (Lereste 1982). As was pointed out earlier, flushing of the upper estuary of the Gambia River by the tides or freshwater flow seems to be insufficient, so that saline waters are permanently trapped upstream from Tendaba during the dry season. Due to high rates of evaporation this stretch of the river may become highly saline after construction of the barrage, when freshwater flow will be almost eliminated from the estuary. Eventually, salinities will exceed that of seawater (a condition called hyper-salinity). The present situation in the Casamance River, as described by Lereste and Odinetz (1984), may serve to illustrate the possible consequences of the Balingho barrage for the Gambia shrimp fishery. As a result of a decrease in rainfall during the past fifteen years, salinities in the Casamance estuary have become so high that migration of juvenile pink shrimp is no longer delayed, but instead the shrimp migrate to the sea at a smaller size. Toward the end of the rainy season in 1983, salinities measured as far upstream as Diattakounda (140 km from the river mouth) exceeded that of seawater at all stations and increased from downstream to upstream. In 1984 the shrimp catches were so mediocre in quantity and quality that two shrimp processing plants near Ziguinchor had to close.

Finally, some consideration should be given to the impact of the Gambian shrimp fishery on the overall productivity of the pink shrimp. Currently, the fishery is concentrated on the estuarine shrimp populations. But, NPE in Banjul

is taking major steps to expand the scope of its activities to the offshore stocks (Josserand 1984). In Senegal, as in most other countries, the penaeid shrimp fishery now exploits both the estuarine and marine shrimp stocks as a result of the decline in shrimp yield from the Senegal River between 1974 and 1976 (Anon. 1978). Overfishing and reduced river flow due to drought were mentioned as possible causes. Estuarine shrimp fishing by means of passive gear such as stake nets primarily concerns the migrating juvenile shrimp. It must be emphasized that each juvenile shrimp that is captured will not be available for reproduction and lost to the offshore shrimp fishery. A penaeid shrimp stock consists mainly of one year class and, even if recruitment occurs throughout the year, it has generally a few distinct maxima. Garcia (1983) states that a typical estuarine shrimp fishery intensively exploits the main group of recruits (3 months old), following it all year around and leaving very few survivors for spawning. The present status of the Gambian shrimp fishery fits this description. It can be assumed that at the age at which the juvenile shrimp are captured, major mortality has already taken place (in particular at the larval stages). The reduction in the numbers of preadults results in an identical reduction (in %) of the total of possible capture offshore (Garcia 1978).

The shrimp catch in The Gambia is maximal during the rainy season, when a maximum number of juvenile shrimp migrate downstream as a result of the annual floods. The catches during this period of the year contain a high number of shrimp, but they are of relatively small size. The second maximum in shrimp catch, toward the end of the dry season, yields a more limited number of shrimp, but of larger size and hence commercial value. To protect the Gambian shrimp stocks from overfishing, it is advisable not to exploit the upstream fishing grounds during the wet season.

In view of the rapid growth and high commercial value of penaeid shrimp, some consideration should be given to the possiblity of estuarine shrimp farming in The Gambia. By constructing ponds in areas where the shrimp occur naturally, the shrimp harvest could be greatly enhanced. In Southeast Asia, salt marshes have been converted into shrimp rearing ponds by excavating and diking. Postlarval shrimp for the ponds are obtained by entrapment from the incoming seawater. At rising tide the sluice gate of the pond is opened, so that the postlarvae enter with the tidal current. Just before the tide turns, the sluice gate is screened and the postlarvae are retained in the pond (Allen 1963). Under experimental conditions the shrimp *Penaeus duorarum* has been reared from egg to adult (Anon. 1963). Although not the most efficient method of shrimp farming, the semi-artificial method described above seems to be the most suitable for a developing country like The Gambia, because investment and management costs are relatively low.

Parapenaeopsis atlantica --

Little is known concerning the biology of *Parapenaeopsis atlantica*, the Guinea shrimp, and no separate catch statistics for this species are available in The Gambia. Part of the recorded shrimp catch in The Gambia is probably made up of Guinea shrimp, in particular from the Banjul area where it is captured by the local fishermen. Some fishery data concerning the Guinea shrimp are recorded from Nigeria, Cameroon, Gabon, Congo, and the Ivory coast, where the best catches are obtained during the period of October-December.

The geographical distribution of the Guinea shrimp is limited to West Africa, where it has been found from Senegal to Angola. It is a coastal species, most abundant at depths from 10-15 m to 40 m. Although common along

the West African coast in shallow waters with a muddy bottom, *P. atlantica* is never very abundant (Crosnier and Debondy 1967). The distribution of the shrimp seems to be linked, according to Monod (1964), to the presence of the warm Guinean waters of somewhat reduced salinity (temperature of 23°-29°C; salinity less than 35 ppt). Unlike the pink shrimp, *Parapenaeopsis atlantica* completes its life cycle at sea and does not seem to need the estuarine environment for its development.

Parapenaeopsis atlantica was found in the trawl samples from the river channel, but not in the catches along the river banks. The Guinea shrimp made up the major part of the shrimp samples from the lower estuary in October (Fig. 26). *Parapenaeopsis atlantica* was less abundant at the end of the annual floods in December, but some increase occurred during the course of the dry season (January-February). The salinity of the lower estuary was somewhat higher in December compared to October, but the temperature of the water was considerably lower (30.3°C in October and 23.1°C in December). Temperature might play a more important role in the distribution of the Guinea shrimp than salinity, because it was found as far upstream as Bai Tenda, where the mean salinity during the dry season was about 11 ppt.

Figure 34 shows the relationship between cephalic length and body length for *Parapenaeopsis atlantica*. The maximum cephalothorax length measured for Guinea shrimp from the Gambia River was 35 mm, with a body length of 120 mm (rostrum not included). No important shifts in the distribution of the size classes appeared in the samples collected in the lower estuary during different hydrological seasons (Fig. 35).

If an offshore Gambian shrimp fishery is developed, the Guinea shrimp will doubtless become more common in the shrimp catches. Furthermore, because of its

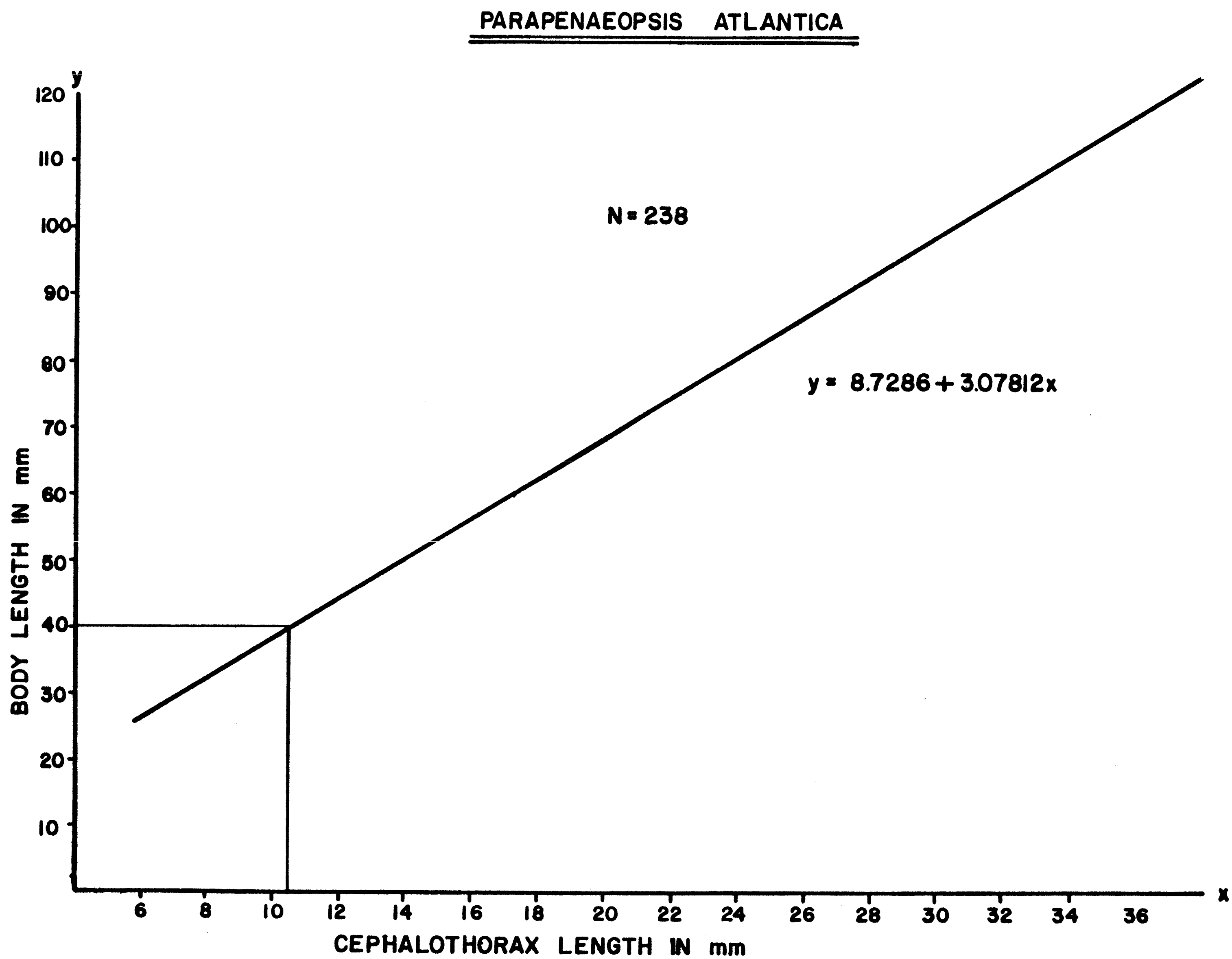


FIG. 34. Relationship between cephalic length and body length for Parapenaeopsis atlantica.

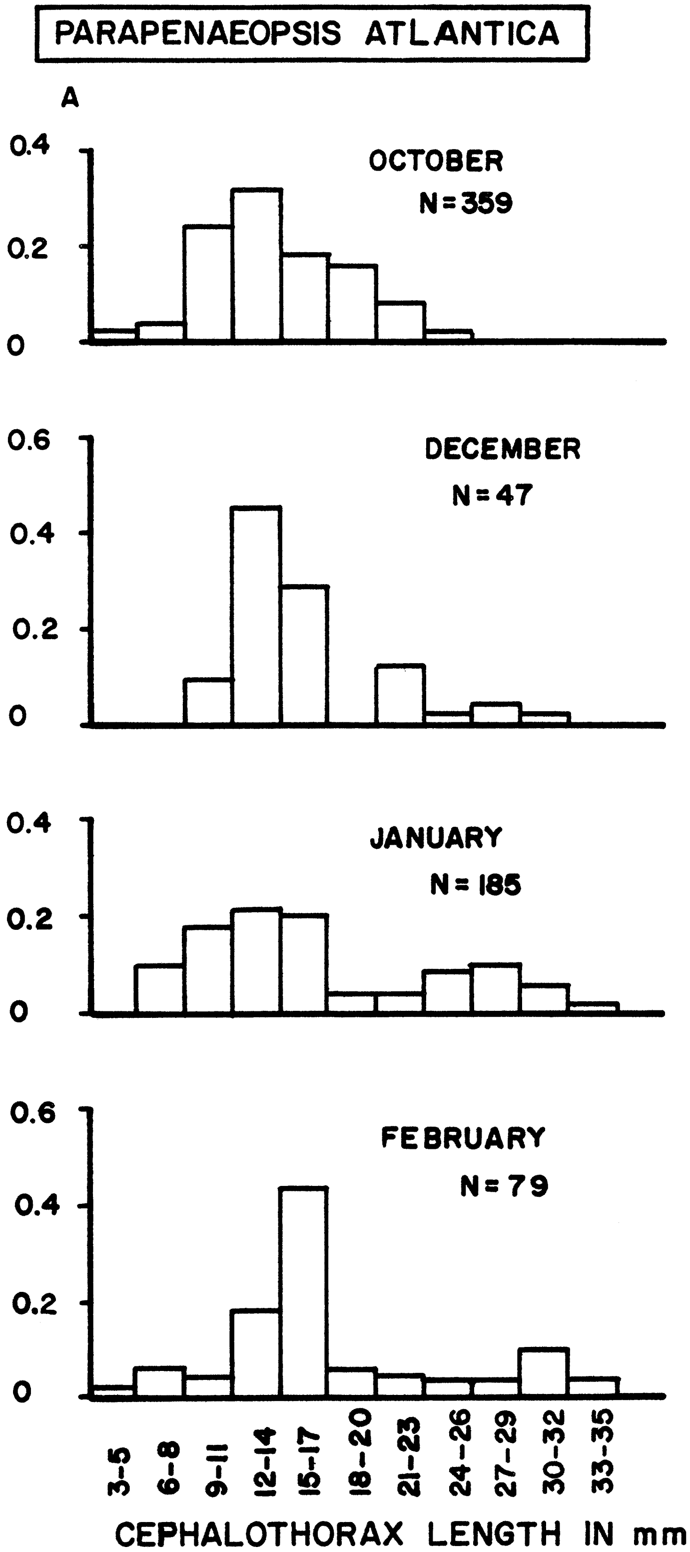


FIG. 35. Distribution of size classes for Parapenaeopsis atlantica in samples collected in the lower estuary during different hydrological periods.

entirely marine life cycle, Parapenaeopsis atlantica does not depend on the estuarine environment for its productivity. For this reason, it will be less vulnerable than the pink shrimp to the changes that will occur in the natural environment as a consequence of the construction of the salinity barrage.

Nematopalaemon hastatus --

The estuarine prawn, Nematopalaemon hastatus, is found in shallow coastal and estuarine waters of West Africa, from Senegal to Angola. Some fishery exists for the prawn in Nigeria where it is captured by means of seining. During the rainy season the catches can be substantial, as much as 500 kg in one seine tow. Too small in size to be of great commercial value, N. hastatus is sold only locally, smoked or dried (Crosnier and Debondy 1967).

The largest estuarine prawn caught in a Gambia River trawl had a maximum cephalic length of 14 mm and a body length of 77 mm (rostrum included). In Figure 36 the relationship between cephalic length and body length (rostrum not included) is shown for this species.

Although absent from the October trawl samples collected near Dog Island (lower estuary), N. hastatus was very numerous in December when the floods declined and March, during the dry season. At those times it made up the bulk of the shrimp samples (Fig. 26). The estuarine prawn was also present in the trawl samples taken during the dry season (March) from the upper estuary. A few ovigerous females were observed, both in the lower and upper estuary (mean salinity of upper estuary about 11 ppt).

Figure 37 shows the size composition of the N. hastatus samples. Important differences were not observed between the samples collected during different hydrological seasons in the lower estuary. The overall size of the prawns

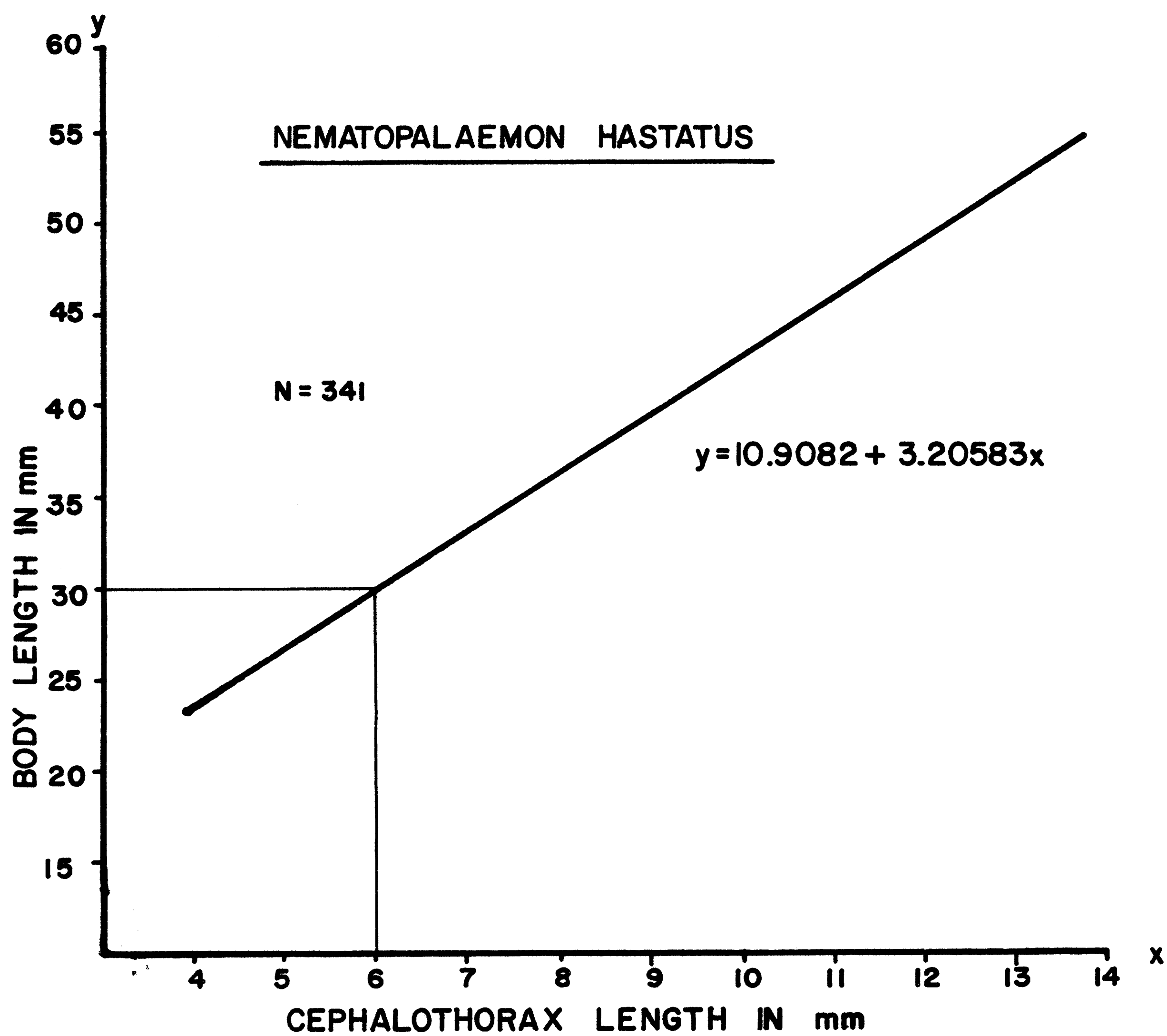


FIG. 36. Relationship between cephalothorax length and body length for Nematopalaemon hastatus.

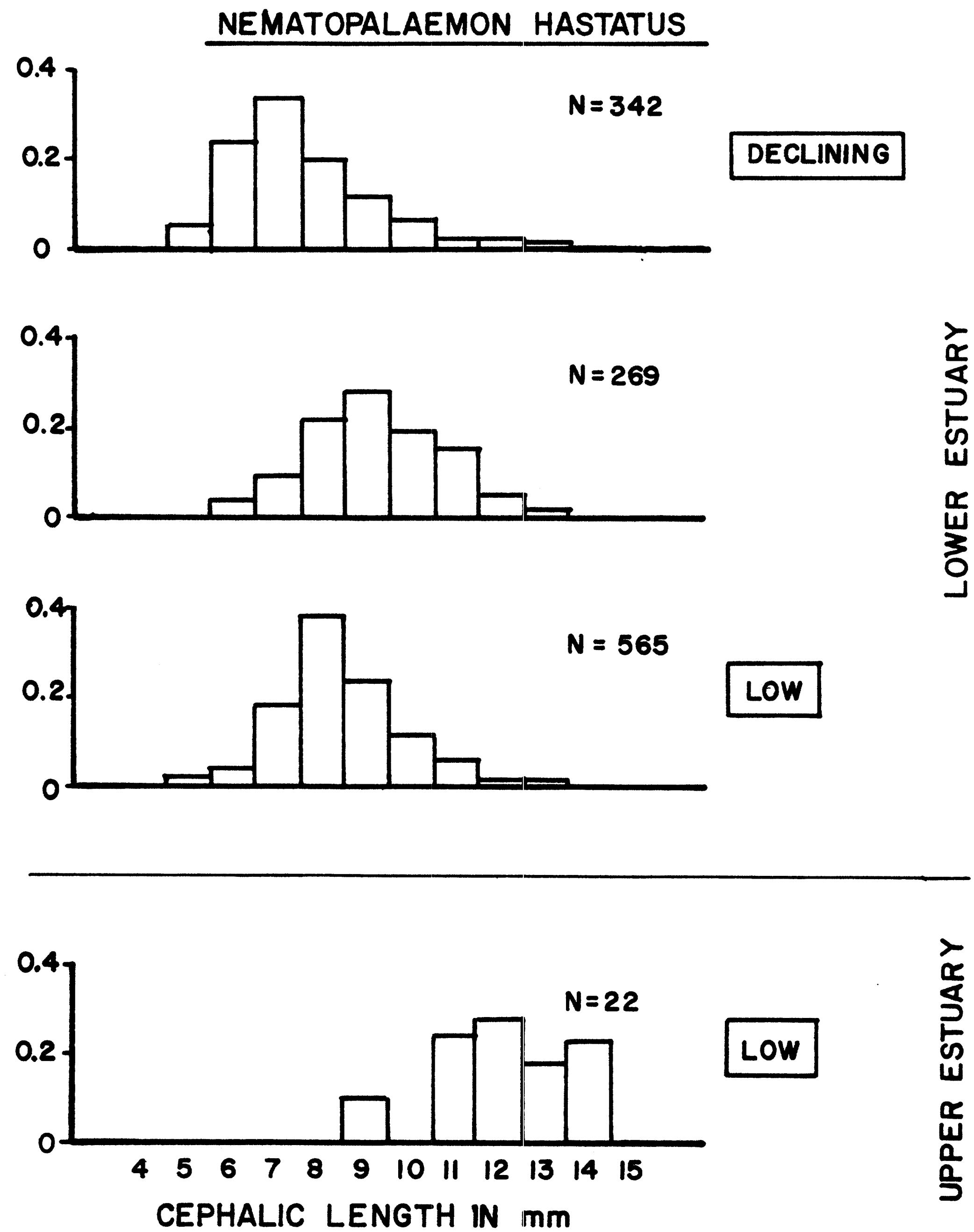


FIG. 37. Size composition of samples of the estuarine prawn from the lower and upper estuary during the declining floods and low water period.

collected in the upper estuary during the low water period was larger than that of the animals captured during the same hydrological season in the lower estuary. Because very few data are available concerning the biology of the estuarine prawn, no explanation can be given for the observed size differences between the two estuarine zones.

Nematopalaemon hastatus has been recorded by Monod (1964) from the Casamance River in southern Senegal. The present observations extend its known area farther North to the Gambia River.

Exhippolysmata hastatoides --

The companion shrimp, *Exhippolysmata hastatoides*, although belonging to a different family, resembles the estuarine prawn to a very large extent in color, shape, and size. The companion shrimp is found in the coastal and marine waters of West Africa on sand and mud bottoms to a depth of about 15 m. No separate catch statistics are available for *E. hastatoides*. In Nigeria it is commonly caught with *Nematopalaemon hastatus* and marketed fresh or smoked (Fisher et al. 1981).

Only sixteen companion shrimp were collected during the Gambia River Study, all of them in the lower estuary (Fig. 26). The cephalothorax length of *E. hastatoides* in the Gambia River varied from 5 to 15 mm, and a maximum body length of 72 mm was measured (rostrum included). Six out of the eight animals caught in January were ovigerous females, with a total body length ranging from 67 to 72 mm. The proportion of *E. hastatoides* with respect to *N. hastatus* was about 3% in January and about 1% in February. Monod (1964) mentioned that in Nigeria the companion shrimp is estimated to make up about 1% of the catches with *Nematopalaemon hastatus*. The finding of *E. hastatoides* in the Gambia River

extends its known distribution area considerably to the north. Before these specimens were collected in The Gambia, it was recorded only from Sierra Leone to Angola (Fisher et al. 1981).

Crabs

Among the crabs found in the Gambia River, only those species belonging to the genus *Callinectes* attain a size sufficiently large to be of commercial value. The following species were collected: *Callinectes amnicola* (= *C. latimanus*), the bigfisted swim-crab; *Callinectes pallidus* (= *C. gladiator*), the gladiator swim-crab; and *Callinectes marginatus*, the marbled swim-crab. A detailed description of the West African swim-crabs is given by Manning and Holthuis (1981). All three species have been recorded from the Baie de St. Jean in Mauritania as far south as Angola.

In the Gambia River very few *C. marginatus* were found in the lower estuary. *C. amnicola* and *C. pallidus* were caught both in the lower and upper estuary. The largest specimen of *C. amnicola* collected during this study had a carapace width of 159 mm; Manning and Holthuis (1981) mentioned a maximum width of 126.5 mm for this species. For *C. pallidus* and *C. marginatus* from the Gambia River maximum carapace widths of 108 mm and 52 mm respectively, were measured. The males of *C. amnicola* and *C. pallidus* were easily distinguished from each other by the length of the gonopods, very long in the first species, almost reaching to the end of the abdomen, but much shorter in the latter species. Distinguishing the females of each species was more difficult, especially when they were immature. Because the length width relation of the carapace appeared to be characteristic for each species, length/width ratios were calculated for

C. amnicola and C. pallidus. Figure 38 shows that the ratio distributions have a distinct range for each species, with hardly any overlap.

In March Callinectes amnicola was very abundant in the upper estuary near Bai Tenda. About 90% of the crabs caught in this river zone were males. In the lower estuary, where this species occurred in much lower numbers, the samples contained only female crabs. Juvenile C. amnicola were found in the bolons (creek) near Bai Tenda; these bolons had a relatively low salinity (mean about 11 ppt) in March. The observations from the Gambia River confirm the data of Charles-Dominique and Hem (1981), who studied the biology of Callinectes in a lagoon in the Ivory Coast. Mating of C. amnicola takes place at low salinities in the estuaries. The fertilized female crabs migrate downstream to the polyhaline parts (>18 ppt) of the estuary, whereas the males stay behind in the oligohaline area. Spawning and larval development occur at salinities above 19 ppt, but growth of the juveniles takes place at the reduced salinities of the upper estuary. The North-American blue crab, Callinectes sapidus, shows a similar migration pattern. Salinity is considered to be an important factor controlling for the survival of the larvae. Hatching does not occur at salinities below 20 ppt (Cargo 1958).

According to Van Engel (1958), it is probable that biggest crabs grow in water of low salt content. This was confirmed by the observations in the Gambia River, for the largest crabs were found at the reduced salinities of the upper estuary.

Contrary to the extensive blue crab fishery existing in the United States, Callinectes is underexploited in West Africa. In Senegal some of the crabs captured in fish nets are sold in the local markets (Reizer 1971). In the Ivory Coast, C. amnicola is an important resource for the local fishermen (total

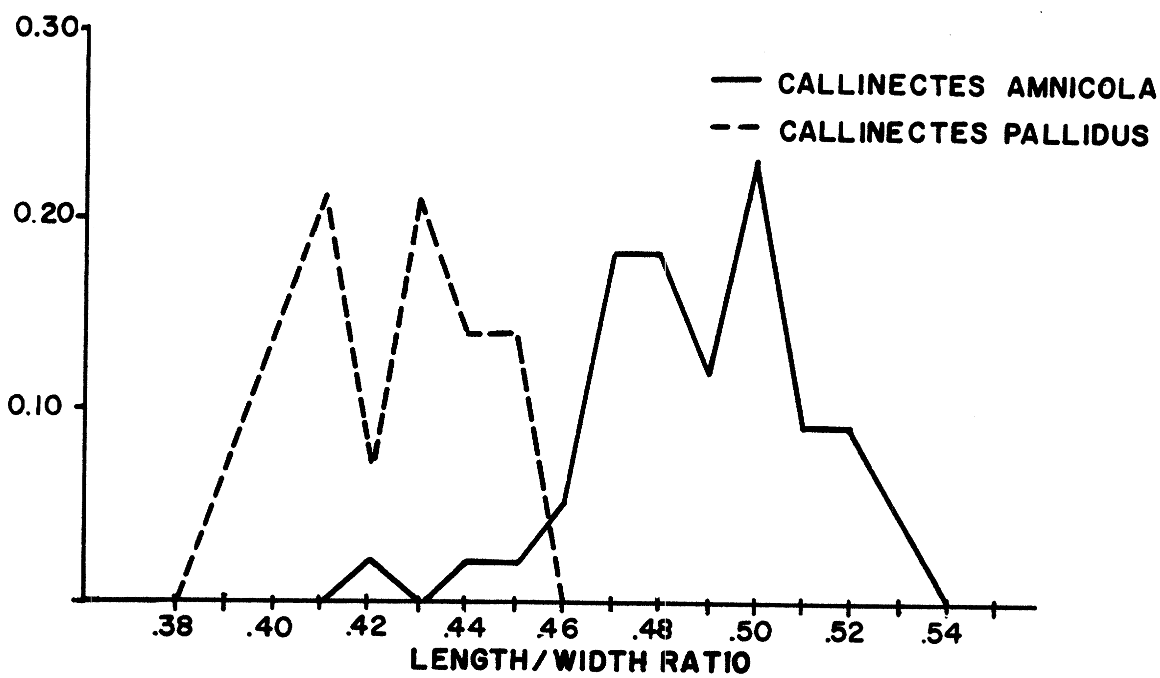


FIG. 38. Relative abundance of length/width ratios for the carapace of Callinectes.

yearly catch may amount to about 1,000 metric tons). But at the same time the crabs are considered a pest, because they destroy the nets when they attack the fish caught in the nets (Durand and Skubich 1982). Various types of gear are utilized to capture Callinectes in the Ivory Coast: gill nets, seines, shrimp nets, etc. The crabs are mainly caught in the shrimp nets, set at night, during ebb tide. These practices primarily harvest the migrating females. The male crab stocks in the oligohaline zones are underexploited. The crabs are usually eaten by the fishermen and not sold (Charles-Dominique and Hem 1981).

The North American Callinectes sapidus (blue crab) is about the same size as the West African C. amnicola, but the former is a very important market crab. No data exist concerning the crab fishery, marketing, or consumption of Callinectes in The Gambia. It is known that some crabs are captured, but only for local consumption. Exploitation of the large adult crab stock available in the upper estuary may be an important contribution to the Gambian economy.
In the United States, blue crab (Callinectes sapidus) is harvested mainly by crab pots, trotlines, dredges, and trawls. For the Gambia River, baited crab pots of simple construction can be used. Pots have several advantages over other gear, such as gill or stake nets. The crabs are more easily removed from the pots compared to the nets, where they become entangled with their legs. Also, the pots are not destroyed by the crabs. During the Gambia River Basin Study, traps made of a wire frame lined with chicken wire proved to be effective gear for catching crabs, at least in the upper estuary. Once the crabs are captured, they should be kept alive in water until sold or processed. Contrary to shrimp, the crabs must be precooked to firm the meat, so that it can be easily removed from the shell for further processing. Meat cannot be readily extracted from crabs that were frozen uncooked (Dassow and Learson 1963).

After construction of the salinity barrage, the permanently high salinities in the upper estuary may adversely affect the growth of *Callinectes*, where growth is enhanced by low salinities. Furthermore, the lack of a positive salinity gradient is likely to exert an important effect on the migratory pattern of the crabs (Cargo 1958).

Mollusks

In the lower estuary of the Gambia River, oysters are collected for local consumption. The oysters, living on the prop roots of the mangrove trees, are harvested by cutting off the roots. Although *Crassostrea gasar* can survive over a wide range of salinities, salinity levels for reproduction must be at least 16.5 ppt. In the warm tropical brackish waters, the oyster *C. gasar* reproduces all year around (Anon. 1980).

Because abundance of *Crassostrea gasar* is directly related to the presence of mangrove trees, reduction in mangrove forests will lead to a decrease in oyster stocks. A major reduction in mangrove forests of the Gambia River will occur after the construction of the proposed salinity barrage. But the mangrove forests are also reduced by cutting trees for firewood and roots to harvest oysters. To compensate for a decrease in oyster stocks and to make the oyster fishery more efficient in The Gambia, simple devices for oyster culture may be installed in places where the oysters occur naturally throughout the year. Among the various methods tested in another West African country, Sierra Leone, the suspended or raft culture was found to be most promising (Kamara and McNeill 1976). The rafts are made of bamboo poles lashed together with wire, and are buoyed by hollow concrete drums or tarred wooden barrels. To collect oyster seed, empty shells are punched and strung on 1.5 to 1.8 m long wires. These are

hung from rafts in oyster breeding areas. The shells with oyster spat are removed from the strings and restrung on wires for raft culture. The material used in Japan for stringing shells is either wire or tarred rice rope. In the latter case, shells are inserted between the layers of rope. When wire is used, the shells are separated by threading hollow bamboo spacers (Quale 1971). Raft culture is an appropriate technique for sheltered places such as the Gambia River estuary, either in the bolons or farther upstream in the main river. Near the river mouth the longline method of oyster culture would be preferable. Longlines have the advantage of withstanding winds, waves, and currents better than rafts. In Japan, where the longline technique is widely applied, strings are suspended from tarred rice ropes, which are supported by barrels that are held apart by anchors.

Anadara senilis, the West African bloody cockle, is mainly collected by women and widely used as food in the West African countries. Mortar is made of its shell. The cockles occur in soft muddy areas of the estuary, where they are collected after locating them by feeling with the feet. No fishery statistics are available for this shellfish, but judged by the heaps of empty shells near the villages, the quantities of cockles collected must be considerable.

Both the oyster and cockle are tolerant of reduced salinities, but to complete their life cycles they need higher salinities during part of the year. However, oysters often suffer considerable predation from drills and starfish at higher salinities (VanSickle 1976). Thus a permanent increase in salinity due to construction of the salinity barrage could have an adverse impact on oyster stocks.

The young cuttlefish, Sepia officinalis hierreda, found in the estuary of the Gambia River, were too small to be of commercial value. The large adult

cuttlefish live off-shore, in deeper waters during the warm season. In the cold season (December-May) they migrate from the deeper areas to the inshore waters to spawn. The female cuttlefish need supports to attach their eggs, and thus assemble in areas rich in algae or grasses, or in places where tree detritus is deposited by rivers (Bakhayokho 1983). During the cold season, large cuttlefish are captured and processed for export by the NPE in Banjul. A decrease in the amount of detritus deposited by the Gambia River in the inshore waters as a result of reduced streamflow could yield a reduction of substrate available for spawning of the cuttlefish and therefore affect the size of the inshore cuttlefish populations.

POSSIBLE IMPACTS OF RIVER IMPOUNDMENT

UPPER AND LOWER ESTUARY

The village of Kuntaur, 250 km upstream from Banjul, is located approximately at the upper-most limit of saltwater penetration in the Gambia River. The mangrove zone below Kauur is unsuitable for agriculture; the soils of the barren mud flats are saline and waterlogged and become highly acidic if dried out. However, as nursery grounds for juvenile penaeid shrimp, the mangroves are very important, offering both shelter and food for young shrimp. Currently, shrimp fishing takes place as far upstream as Jappeni during the dry season. In 1984 the pink shrimp, *Penaeus duorarum*, was caught even farther upstream, near Bambali; the Guinea shrimp, *Parapenaeopsis atlantica*, was found as far as Bai Tenda (Fig. 39).

As discussed above, the construction of the salinity barrage near Balingho will have a major impact on the Gambian shrimp fishery. Upstream from the barrage, 8,700 hectares of mangrove forest will die as saline water becomes a

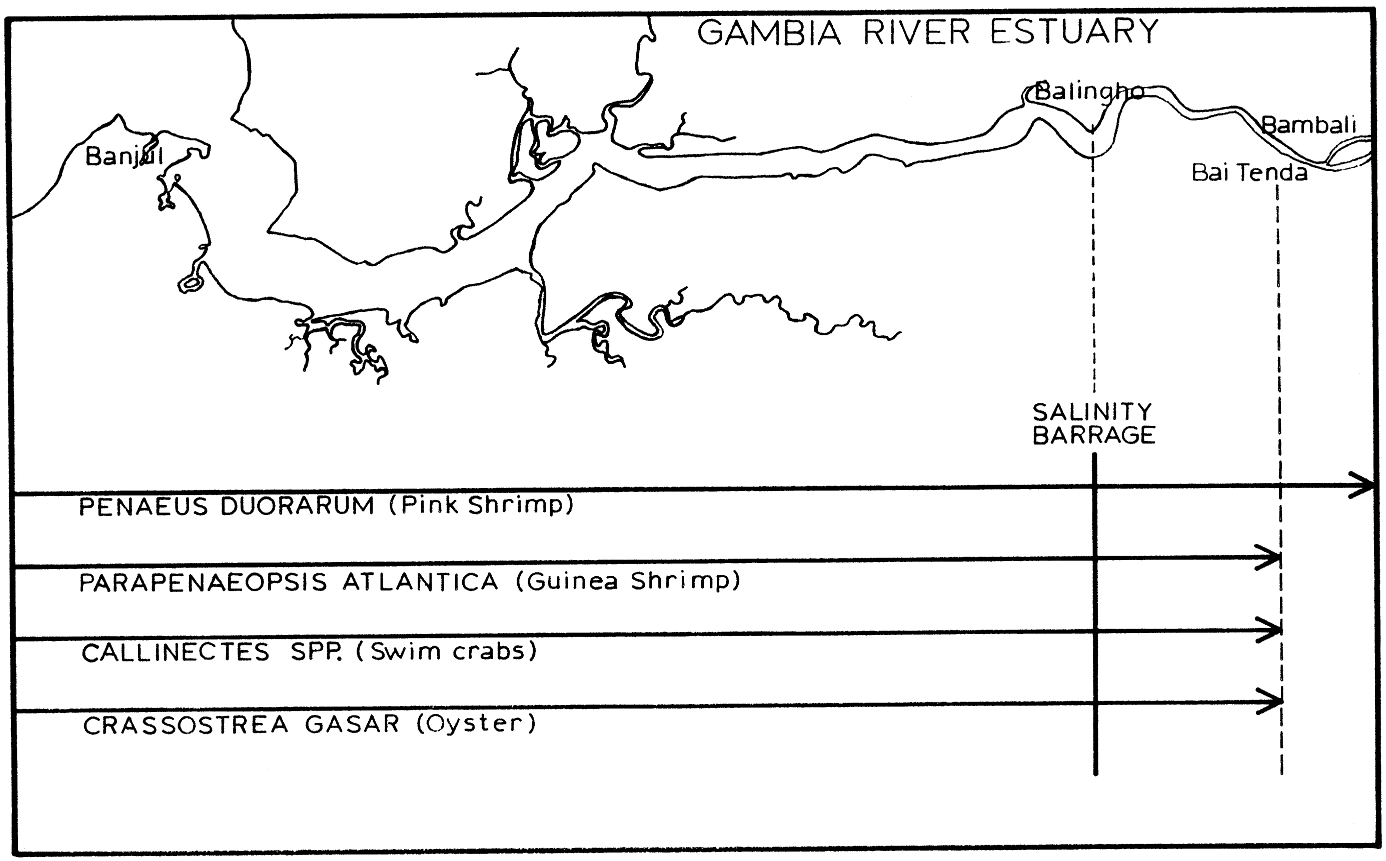


FIG. 39. Upstream distribution limits of commercially important shrimp, crab, and oyster species in the Gambia River, with respect to the site of the future salinity barrage.

freshwater lake. Shrimp stocks will be eliminated from that area, because penaeid shrimp cannot live in permanently fresh water. Moreover, no new juvenile shrimp will be recruited from the lower estuary, because the dam forms a barrier to their migratory route. A yearly loss of almost 10% of the total shrimp catch in The Gambia can be expected after construction of the barrage. In 1983, the total amount of shrimp caught near and upstream from Balingho was 31.8 metric tons (Table 8). The shrimp catch recorded for part of 1984 (January to mid-August) in this stretch of the river is already more than 61 metric tons, which represents a value of 732,000 Dalasis. The shrimp are sold at NPE shrimp factory for 12 Dalasis a kilogram.

Figure 40 summarizes the life cycle of the pink shrimp, Penaeus duorarum, and changes in the natural environment resulting from river impoundment that will directly affect the shrimp's different developmental stages. Downstream from the barrage, due to a very reduced river flow, polyhaline salinities will prevail throughout the year. Negative impacts of a permanently increased salinity are not expected on the shrimp populations. But changes in the mangrove vegetation and in the composition of food available to the young shrimp, as a result of changed salinity, might affect the shrimp stocks. The absence of a sudden large increase in freshwater discharge during the wet season will result in a delayed downstream migration of pre-adult shrimp toward the sea. A very reduced freshwater outflow near the river mouth might lead to a decrease in the number of postlarvae entering the estuary. The arrival of a low salinity current at sea orientates the postlarval shrimp in the direction of the river mouth.

Another aspect of the planned river basin devlopment program will be an increased use of fertilizers, pesticides, and herbicides. Contamination of the

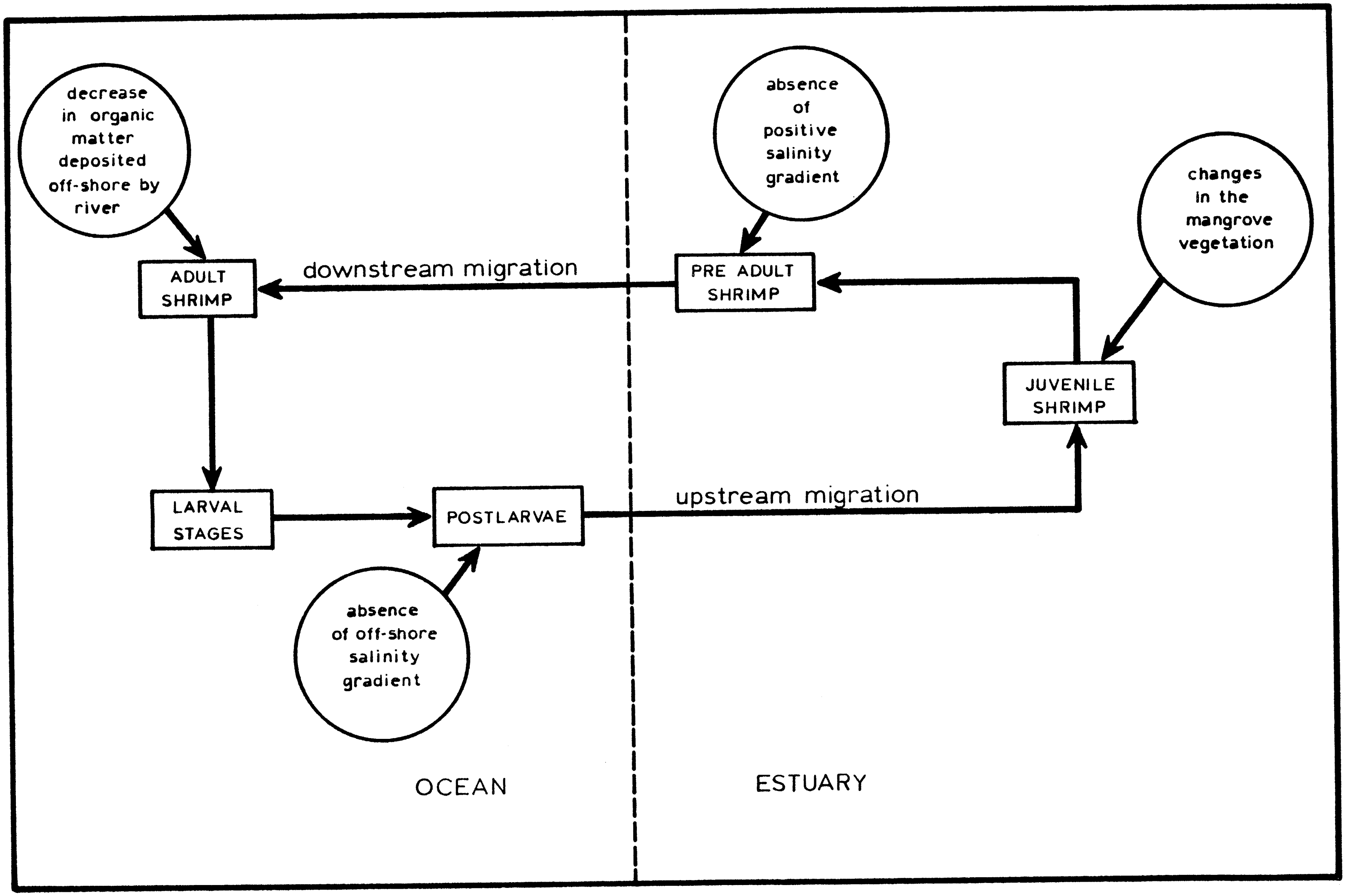


FIG. 40. Life cycle of the pink shrimp *Penaeus duorarum* and changes in the natural environment as a result of stream flow regulation that will affect the different developmental stages.

river by drainage water from the irrigation schemes might severely affect the estuarine shrimp populations, as well as other invertebrates. There is evidence from laboratory experiments that even at very low concentrations many substances from industrial waste or used as pesticides are lethal to shrimp (Kutkuhn 1966).

The impact of the salinity barrage with respect to the commercially important shrimp populations (*Penaeus duorarum* and to a lesser extent, *Parapenaeopsis atlantica*) can be summarized as follows: Shrimp will not be found upstream from Balingho. The normal detritus-based food supply will be disrupted. The maximum size of the shrimp occurring in the river will probably increase as a consequence of a delayed seaward migration of the pre-adult shrimp. Increased use of toxic substances in agriculture and for public health might have an adverse effect on the estuarine shrimp stocks.

Measures which could be taken to mitigate the adverse impacts of the dam construction on the estuarine shrimp fishery include a highly controlled use of fertilizers, herbicides, and pesticides, so that these substances will not attain concentrations in the river water to impair the quality and quantity of the shrimp stocks. Furthermore, the shrimp nursery grounds of the Gambia River estuary should be protected from overfishing. Some of the current shrimp fishing stations should be abandoned following the example of the Kamobeul bolon, a tributary of the Casamance River and an important nursery area for pink shrimp. Fishing of juvenile shrimp is forbidden in this bolon. The size of the adult shrimp stock, living in the shallow waters along the West African coast, depends on the recruitment of pre-adult shrimp mainly from the Casamance estuary and to some extent from the Sine Saloum, north of The Gambia. In comparison, the amount of pre-adults provided by the Gambia River is the lowest of the three rivers (Anon. 1980). This might partially be explained by overexploitation of

estuarine shrimp stock in the Gambia River. The fishery principally concerns shrimp varying in sizes from 10 to 20 cm, which corresponds to the size classes of pre-adult animals migrating down the river to spawn at sea.

The crab populations of the genus Callinectes, although commercially much less important than the penaeid shrimp, will be greatly affected by the construction of the salinity barrage. Callinectes, now very numerous near Bai Tenda in the upper estuary, will completely disappear from that part of the river (Fig. 39). Because the crabs do not seem to require low salinities to complete their life cycle, the main result from the barrage will be a shift in seaward direction of their upstream distribution limit. Callinectes shows a migration pattern similar to that of the pink shrimp, and a permanently reduced freshwater flow may result in delayed downstream migration of the female crabs. Higher salinities will impair the growth rate of the male crabs which stay behind in the upper estuary.

The oyster, Crassostrea gasar, occurs as far upstream as Bai Tenda (Fig. 39). Increased salinity in the estuary below the barrage will have a beneficial effect on the growth of oysters in this part of the river. However, the crab Callinectes is known to be an oyster predator (Lunz 1947), so that, together with an increase in the oyster populations, heavy predation by the crabs on oyster spat might occur. The stabilization of estuarine salinity levels from stream flow regulation may also favor the oyster drill, a parasite of oysters, which normally is eliminated by the annual floods and reduced salinity (Gunter 1955, VanSickle et al. 1976).

While there is no doubt about the disappearance of the mangrove forests upstream from the Balingho barrage, where freshwater conditions will be permanent, it is difficult to predict how the increase in salinity downstream

from the dam will affect the mangroves. Because many of the species that make up the mangrove vegetation cannot thrive without some freshwater influence (Snedaker 1978, Saenger et al. 1983), a reduction in the vegetation cover may occur following construction of the barrage. Compared with the mangrove forests in the upper estuary, the mangrove trees near the river mouth, where marine salinities prevail, are much shorter and less luxuriant. The productivity of mangroves is related to the periodicity and frequency of tidal flushing and inundation by fresh waters. Periodic flushing prevents a deleterious buildup of salinity. The most complete flushing of excess salts occurs during the rainy season. A reduced freshwater influence can have a profound effect on the zonation and distribution of mangrove species via increased salinity. The risk of loss of mangrove area due to salinity intrusion is even higher in acid regions (Johnson 1978). Any changes that will occur in the mangrove vegetation either directly (protection) or indirectly (availability of food) affect the productivity of shrimp and other invertebrates inhabiting the estuary.

The high productivity of estuaries appears largely due to the continuous supply of organic matter from the mangrove forests which line the river. The leaf litter from the mangrove trees that enters the estuarine system forms the basis for a complex food web. The rich nutritional conditions provide the basis for estuarine fisheries (McLusky 1971). Thus flow regulation of the Gambia River may affect the overall productivity of the estuarine and coastal waters from a decreased supply of nutrients.

Major changes in the composition of the invertebrate bottom fauna of the lower estuary are not expected following the construction of the salinity barrage. Without exception, the invertebrates composing the benthos near Dog Island are marine species. The more stenohaline species might be favored by a

salinity that remains high throughout the year, so that a slight shift in relative abundance among the invertebrates of the lower estuary will take place. Also, marine invertebrates now restricted to the river mouth area will be able to penetrate farther upstream into the estuary.

LOWER RIVER

The lack of diversity in substrate, depth, and current velocity in the river near Bansang is reflected in the rather poor benthic fauna in this portion of the Gambia River. The water remains fresh throughout the year, so that no impact can be expected from the elimination of saline waters upstream from the Balingho Salinity Barrage. Regulated stream flows from discharge of upstream dams might lead to the creation of shallow water habitats now absent from the lower river. The formation of new habitats within this river zone will result in an increase in the diversity of bottom fauna, as more ecological niches will be available. An increase in nutrients induced by the arrival of drainage water from the irrigated fields will enhance the overall productivity of the lower river.

KEKRETI DAM SITE

Creation of a reservoir upstream from the Kekreti dam will change the present riverine biotope into a limnetic environment. Changes in the community structure of both vertebrate and invertebrate fauna will take place after impoundment. The isothermal river regime will be modified into a thermally stratified regime, characteristic of lakes. This will induce a vertical concentration gradient of chemical components. Microbial decomposition of accumulated organic matter at the lake bottom will produce oxygen depletion in

the bottom layers of the water. Near the surface of the water and in the shallow parts of the reservoir, macrophytes and algae will develop. This production of organic matter will constitute a continual input of nutrients for the bottom water. A high nutrient concentration coupled with oxygen depletion will result in reduction of nitrates to ammonia, of sulfate to hydrogen sulphide, and iron and manganese may attain toxic levels (Agrar-Und Hydrotechnik GMBG and Howard Humphreys Ltd. 1983).

In Lake Volta, the benthic invertebrates show changes in vertical distribution according to the time of the year. Following the onset of the floods, the vertical stratification of the lake is disrupted and the benthic invertebrates are able to spread over the deeper parts of the reservoir (Petr 1969). A similar spatial distribution of bottom fauna is to be expected in the Kekreti reservoir. During the early stages of reservoir formation, a considerable increase in nutrients will take place due to the decomposition of submerged terrestrial vegetation, resulting in a high primary productivity. Consequently, the overall abundance of benthos will increase as well. Those animal groups among the present bottom fauna that are already living in a stagnant or slow running river habitat will be best adapted to lake conditions and they will increase in abundance in the reservoir. The appearance of macrophytes in the lake will provide a new substrate to the invertebrate fauna. In particular, gastropod mollusks will benefit from the presence of rooted and floating vegetation, together with stagnant water conditions.

If clearance of terrestrial vegetation is not conducted before flooding of the reservoir area, substrate suitable for benthic invertebrates will be provided by the submerged tree and shrubs. In man-made Lake Kariba, at least twice as much tree-surface area as lake bottom area is available to the

invertebrate fauna (McLachlan 1970). The wood-boring nymphs of the mayfly *Povilla adusta*, now only present in low numbers in the river near Kekreti, will particularly be favored by the presence of a large amount of submerged wood. A considerable increase in abundance of this species can be predicted, as was the case in Lake Volta, where no clearance of the terrestrial vegetation took place prior to river impoundment (Petr 1970a). Similar to the Gambia River near Kekreti, *Povilla adusta* was not common in the original Volta River, but rapidly colonized the lake after its creation. This mayfly can become an important link in the food web of the Kekreti reservoir, since it is readily eaten by many fish species.

Typical blackfly breeding habitats do not appear to exist at the Kekreti dam site. Although current velocities were rather high in some parts of the river in December, the water might have been too deep to offer a suitable environment for blackflies to breed. Following the construction of the Kekreti dam, blackfly populations will increase downstream, with the appearance of shallow rapids as a consequence of regulated streamflows. Moreover, the fast running well-oxygenated waters of the spillway of a river dam can offer a small but very suitable habitat for blackfly larvae (Lewis 1966). Discharged bottom water from the Kekreti reservoir, characterized by low oxygen levels and a high hydrogen sulphide and mineral component concentration, might have a lethal effect on river life as far downstream as 7 to 10 km from the dam (Agrar-Und Hydrotechnik GMBG and Howard Humphreys Ltd. 1983). Furthermore, fertilizers, herbicides and pesticides may attain high concentrations in the river to the detriment of the aquatic fauna, especially the invertebrates, which cannot readily escape from a polluted area. Dejoux (1982), who studied the impacts of the insecticide temephos (commonly used against blackfly), on the survival of

other aquatic macroinvertebrates, observed a very high mortality among the benthic invertebrates. The drainage water from the irrigation schemes may have an adverse effect on river life by its high concentration of toxic substances. But, this same drainage water will also provide an additional influx of nutrients increasing the productivity of the river.

UPPER RIVER

The Gambia River near Kedougou offers a variety of micro-environments, reflected in the presence of a diversified benthic fauna. The regulating action of the Guinean dams on the streamflows will reduce the seasonal fluctuations between massive floods and a very restricted water course. As a result of more stable hydrological conditions, animals belonging to the permanent fauna, for example, the crab *Potamonautes ecorssei*, mollusks, and oligochaets, may become more common than they are at present. A relatively constant water level and stream velocity will allow the establishment of aquatic macrophytes, now almost absent from the river bed. Development of rooted vegetation together with fast running water will increase the breeding possibilities for Simuliidae, vectors of onchocerciasis. Blackfly larvae and pupae were mainly found on dead leaves trapped behind stones in the rapids. If the current velocities of the regulated streamflows are high, appropriate breeding conditions for blackflies will occur during a longer period of the year. Thus, an overall increase in blackfly populations near Kedougou can be expected after the river has been impounded upstream.

HEADWATERS

The composition of the invertebrate bottom fauna and the relative abundance of the different taxa in the headwaters zone of the Gambia River in Guinea resemble to a large extent those mentioned by Petr (1970b) for the Black Volta River in Ghana. The benthos in the Guinean headwaters consisted mainly of insect larvae and imagoes, a temporary fauna. Current velocity appears to be the most important physical factor responsible for the quantitative and qualitative differences in bottom fauna observed in various river habitats. During the declining floods, the current distribution was very heterogeneous, thus creating a variety of micro-environments within the river zone. The existence of a particular type of bottom substrate was determined by the stream velocity. The increase in current and amount of water during the rainy season resulted in a complete washing out of all small particles of mud, sand, and fine gravel deposited during the dry season. At the end of the rainy season stones prevailed in the bottom substrate. During the floods, adult aquatic insects cannot deposit their eggs directly on the substrate. Also, mechanical destruction of the invertebrate bottom fauna takes place, when the river is greatly disturbed by the fast current. The river bed can only be recolonized when the floods decline and the water level is sufficiently low and the bottom substrate stable again.

The invertebrate fauna of the riverine rapids will be almost completely destroyed in the reservoirs with the creation of a permanently flooded, stagnant water area. Blackflies, currently a main component of the invertebrate river fauna in Guinea, will disappear upstream from the dams.

If clearing of the abundant Guinean woodlands does not take place prior to flooding of the dam reservoirs, the submerged trees will form a major substrate

for invertebrate fauna. Soon after flooding the tree trunks become encrusted with algae and other "Aufwuchs." Investigation of the stomach contents of the most important commercial fish species in Lake Volta showed periphyton to be a relatively unimportant part of the fish diet (Lawson et al. 1969). The indirect importance of periphyton development is that it provides food for macroinvertebrates, which in turn are eaten by the fish. The wood-boring mayfly Povilla adusta, although not found at the sampling site in the Republic of Guinea, will doubtless become very common in the reservoirs if submerged trees are available. Povilla nymphs are of great importance in the conversion of algae into fish, being themselves heavily exploited by fish in man-made lakes. The development of rich populations of Povilla adusta in Lake Volta has been reflected by changes in the fish fauna. Fish species exploit the invertebrates living on the submerged trees and have been found to feed preferentially on wood-boring mayfly nymphs. In reservoirs with a large amount of trees, this mayfly constituted over 90% by biomass of all macroinvertebrates present (Petr 1969).

The bark surface of submerged trees also offers a very suitable habitat to chironomid larvae, so that an increase in abundance of these insects can be expected following river impoundment. McLachlan (1970) showed that chironomid larvae begin to settle on the wood within 24 hours of immersion of freshly-cut branches in Lake Kariba. Some invertebrate groups which live in the fast running, well-oxygenated parts of the stream, such as the Orthocladiinae (Diptera), will adapt to the lake environment by establishing themselves on submerged trees that are continuously exposed to wave action (Petr 1970b).

According to McLachlan (1970), a littoral woodland zone can be distinguished, lying between the minimum and maximum levels of the reservoir and being characteristic of the second phase in lake development after the filling of the

reservoir has taken place. Following the first recession in water level, the exposed dead trees can be attacked by terrestrial wood borers (mainly beetles). After reimmersion of the littoral woodland, an additional habitat under the bark of the trees is available to aquatic invertebrates. The invertebrate aquatic fauna of the trees standing in the hypolimnion of the lake, which are permanently submerged, remains aquatic all year.

Lakeflies (Chaoboridae), which are only found in the relatively deep waters of the upper estuary and lower Gambia River, will be able to colonize the deeper parts of the reservoirs. In the deep waters of Volta Lake, where chironomid larvae can no longer live because of low oxygen levels, large populations of Chaoboridae have developed (Petr 1969).

The banks of the Gambia River and its tributaries in the headwaters zone are, for the most part, steep. Because of the mountainous character of the area, dam construction can be expected to result in the creation of lakes with steep shelving shores, in particular at the Kouya dam site, located on the Gambia River upstream from its confluence with the Litti. This dam is planned to be more than 100 m high and will close a narrow passage in the river valley. The submerged soils of the dam reservoirs will undergo changes as a result of shoreline erosion, deposition of organic debris, and influence of river sediments.

In Lake Kariba the distribution of bottom fauna appeared to be influenced by shoreline type and thermal stratification. The latter caused the benthos to be completely absent from the anaerobic hypolimnion during the warm season. In winter, following the turnover of the lake, a substantial chironomid population had colonized the profundal mud (McLachlan and McLachlan 1971).

The annual drop in the level of the reservoir (drawdown), caused by the opening of the sluice gates in order to provide water for hydroelectricity and irrigation, has an important impact on the fauna and flora in the littoral zone of the lake. In the drawdown zone, sedges (Cyperaceae) and other rooted emergent plants adapted to fluctuating water levels will spread. The shrub Rotula aquatica, already well established in the upper course of the Gambia River, will probably invade the shores of the Guinean reservoirs. With the development of macrophyte vegetation in the shallow areas of the reservoirs, an increase in the abundance of aquatic snails, very uncommon at present in the headwaters, can be expected. In Lake Volta the snail Bullinus, an intermediate host of Schistosoma, became a substantial part of the total biomass of benthic fauna among the vegetation of the lake (Petr 1969).

Differences in the composition and relative abundance of the benthic fauna will occur during the successive stages of the lake formation. During the filling period of the reservoir, a rapid increase in nutrients resulting from the decomposition of terrestrial vegetation may lead to algal blooms. Chironomid larvae will prevail during this phase. After some months, softened submerged wood can be attacked by the nymphs of Povilla adusta. This mayfly will rapidly increase in abundance. With the disappearance of the submerged trees by decay, the biomass of Povilla will decrease, but chironomid larvae will still dominate the invertebrate benthic fauna of the reservoir. In general, with increasing stabilization of the lake environment, species diversity will become higher and seasonal influence on lake productivity will become manifest (Freeman 1974).

Downstream from the Guinea dams, diminished and more regular streamflow will result in the formation of habitats that are suitable for breeding of

aquatic insects throughout the year, whereas now they can only breed during the dry season. At present, macrophytes are rather scarce in the headwaters zone. Although most stones in Guinea were covered with the moss-like *Tristicha*, larger plants such as *Polygonum* were rare. A more stable streamflow will favor the development of rooted aquatic vegetation and gastropods, both of which are currently only trivial segments of the aquatic biota. The appearance of aquatic plants in the fast flowing parts of the river will increase the breeding possibilities for Simuliidae. Moreover, dam construction may create new blackfly habitats; not only the spillways, but other components of the dam can offer a suitable breeding environment for blackflies, as was pointed out by Lamontellerie (1967) with respect to the Garango dam in Upper Volta.

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